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12 SEP 2007

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SUBJECT: GROUNDWATER MONITORING WELL INSTALLATION AND SAMPLING  
REPORT FOR ORION PARK HOUSING AREA, MOFFETT COMMUNITY  
HOUSING, MOFFETT FIELD, CALIFORNIA, SEPTEMBER 12, 2007

Dear Ms. Wells and Ms. Lee:

The final *Groundwater Monitoring Well Installation and Sampling Report for Orion Park Housing Area* is enclosed.

This report describes groundwater monitoring well sampling results and other results related to the Orion Park Housing Area. Comments on the August 4, 2006, *Draft Groundwater Monitoring Well Installation and Sampling Report* have been incorporated in this report as appropriate.

Please contact me at 619-532-0963 if you have any questions.

Sincerely,

DARREN NEWTON  
Base Realignment and Closure  
Environmental Coordinator  
By direction of the Director

Enclosure: 1. Groundwater Monitoring Well Installation and Sampling Report  
for Orion Park Housing Area

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**GROUNDWATER MONITORING WELL  
INSTALLATION AND SAMPLING REPORT  
FOR ORION PARK HOUSING AREA  
September 12, 2007**

**MOFFETT COMMUNITY HOUSING  
MOFFETT FIELD, CALIFORNIA**

Base Realignment and Closure  
Program Management Office West  
1455 Frazee Road, Suite 900  
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CONTRACT NO. N68711-98-D-5713  
CTO No. 0079

**GROUNDWATER MONITORING WELL  
INSTALLATION AND SAMPLING REPORT  
FOR ORION PARK HOUSING AREA  
September 12, 2007**

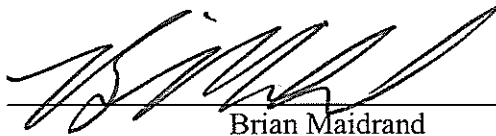
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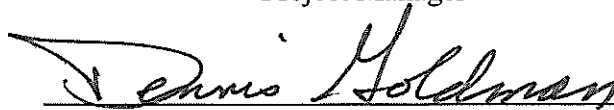


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## ABBREVIATIONS AND ACRONYMS

$\delta$	delta notation; permil (‰) deviation relative to a reference standard
1,1-DCE	1,1-dichloroethene
$\mu\text{g/L}$	micrograms per liter
$\mu\text{mhos/cm}$	micromhos per centimeter
ASTM	American Society for Testing and Materials
bgs	below ground surface
C	carbon
cis-1,2-DCE	cis-1,2-dichloroethene
Cl	chlorine
CPT	cone penetrometer test
CSM	Conceptual Site Model
DoD	Department of Defense
DOT	Department of Transportation
DPT	direct push technology
EPA	U.S. Environmental Protection Agency
ft/ft	foot per foot
FWENC	Foster Wheeler Environmental Corporation
GC/IRMS	gas chromatography/isotope ratio mass spectrometry
H	hydrogen
HDPE	high-density polyethylene
IDW	investigation-derived waste
IT	International Technology Corporation
J	estimated value
L/min	liters per minute
meq/L	milliequivalents per liter
MEW	Middlefield-Ellis-Whisman
mg/L	milligrams per liter
MS/MSD	matrix spike/matrix spike duplicate
msl	mean sea level
NAD	North American Datum

## **ABBREVIATIONS AND ACRONYMS**

(Continued)

NASA	National Aeronautics and Space Administration
OPHA	Orion Park Housing Area
permil	per thousand (‰)
PCE	tetrachloroethene
pH	hydrogen ion concentration
PID	photoionization detector
ppm	parts per million
PVC	polyvinyl chloride
QC	quality control
RPD	relative percent difference
SAIC	Science Applications International Corporation
SCVWD	Santa Clara Valley Water District
SIG	The SI Group
SMOC	Standard Mean Ocean Chloride
TCE	trichloroethene
trans-1,2-DCE	trans-1,2-dichloroethene
TtFW	Tetra Tech FW, Inc.
USCS	Unified Soils Classification System
VC	vinyl chloride
VOC	volatile organic compound
Water Board	California Regional Water Quality Board
WATS	West-Side Aquifers Treatment System

## EXECUTIVE SUMMARY

This Groundwater Monitoring Well Installation and Sampling Report for Orion Park Housing Area (Report) describes the results of groundwater monitoring well installation and sampling activities performed at the Orion Park Housing Area (OPHA). OPHA is part of the Army's Moffett Community Housing (Community Housing) and was part of the former Naval Air Station Moffett Field (Moffett), Moffett Field, California. The Navy transferred the Community Housing to the Air Force in 1994. The Community Housing was subsequently transferred to the Army in July 2000.

OPHA is located south of the San Francisco Bay in the Santa Clara Valley, near the cities of Mountain View and Sunnyvale. OPHA consists of approximately 72 acres. Historical land use at OPHA was primarily agricultural. OPHA was developed with residential housing and support facilities for Department of Defense personnel. Volatile organic compounds (VOCs), primarily trichloroethene (TCE) and its breakdown product cis-1,2-dichloroethene (cis-1,2-DCE), have been previously detected in groundwater samples collected from the upper and lower portions of the A aquifer at, and upgradient of, OPHA.

Eleven groundwater monitoring wells were constructed on OPHA in August 2005: six in the upper portion of the A aquifer (upper A aquifer) and five in the lower portion of the A aquifer (lower A aquifer). The 11 OPHA groundwater monitoring wells, along with three existing wells located east of OPHA were sampled for VOCs, anions, cations, and for stable isotope ratio analyses in August and December 2005. The same 14 wells were also sampled in March and June 2006 for VOCs. Depth to groundwater measurements were also collected.

The upper and lower portions of the A aquifer are hydraulically connected, yet hydrostratigraphically different. The upper A aquifer consists of interconnected coarser-grained sands and gravel with layers of finer-grained silty sand and sandy silt, thus providing a preferential migration pathway south to north across the site. Groundwater flow direction in the upper A aquifer is relatively consistent across OPHA from south-southeast to north-northwest. The lower A aquifer generally consists of finer-grained silty sand and sandy silt that are not as laterally continuous or as interconnected as upper A aquifer coarse-grained soil layers. The lower A aquifer contains more extensive silt layers than the upper A aquifer. Finer-grained soil in the lower A aquifer causes the general north-northwest groundwater flow direction to shift to the north-northeast in the west-central portion of the site.

TCE concentrations in all monitoring wells appear to show seasonal variation and a slight downward trend in concentration over the four quarters of measurements.

TCE and cis-1,2-DCE are migrating onto OPHA in the upper A aquifer, across the southern border. Relatively consistent TCE and cis-1,2-DCE concentrations were detected at the southern

OPHA border, throughout the length of OPHA, and onto National Aeronautics and Space Administration property, along a band trending south to north. The TCE and cis-1,2-DCE migration pathway follows the contiguous zone of coarse-grained soil layers in the upper A aquifer and the groundwater flow direction.

Similar to the upper A aquifer, TCE is migrating onto OPHA, in the lower A aquifer, across the southern border. The lower A aquifer TCE distribution pattern suggests that migration of TCE is influenced by local groundwater flow direction and hydrostratigraphy. The preferential contaminant migration pathway flows northward onto OPHA across the southern boundary, moves northward along the western OPHA boundary, then to the northeast, following the groundwater flow direction and the coarse-grained soil layers, to the west-central portion of the site.

The stable isotope data are interpreted as showing three isotopic ratio signatures, thus three TCE sources affecting the groundwater beneath OPHA. The three sources originate off site and upgradient of OPHA. No on-site TCE sources have been identified, and there is no evidence to suggest an on-site source.

A conceptual site model (CSM) was developed using multiple lines of supporting evidence. The multiple lines of evidence include: 1) local hydrostratigraphy; 2) upper and lower A aquifer VOC distribution patterns; 3) local groundwater flow direction; 4) stable isotope study results; and 5) historical and current land use. The CSM includes instantaneous or short-time off-site release(s) of TCE south of OPHA responsible for the majority of OPHA TCE and cis-1,2-DCE concentrations. The resulting groundwater TCE “slug(s)” migrated downgradient within the upper and lower A aquifer, with residual contamination from the source and the tails of the slug(s) stretching back to the source area. The slugs move at different rates: faster in the upper portion of the A aquifer compared to the lower portion. Over time and distance, the slugs lose mass as they are subjected to the chemical and physical processes of degradation, dilution, dispersion, and sorption. Due to the higher transport rate in the upper A aquifer, the slugs have migrated through OPHA leaving only the residual “tail of the TCE plume” and one slug remnant observed as a slightly elevated concentration (sorption/desorption from finer-grained soils). In the lower A aquifer, due to the slower transport rate and discontinuous coarse-grained layers, a portion of the slugs are still present in the central OPHA.

## **1.0 INTRODUCTION**

Volatile organic compounds (VOCs) were detected in the groundwater upgradient, beneath, and downgradient of the Orion Park Housing Area (OPHA) during previous investigations. The Navy installed 11 groundwater monitoring wells at OPHA in August 2005, and completed four rounds of groundwater gauging and sampling (August and December 2005, and March and June 2006). This Groundwater Monitoring Well Installation and Sampling Report for Orion Park OPHA (Report) describes the results of groundwater monitoring well installation and sampling performed at OPHA.

OPHA is located in the southwestern portion of former Naval Air Station Moffett Field (Moffett). Moffett is located south of the San Francisco Bay in the Santa Clara Valley, California, near the cities of Mountain View and Sunnyvale (Figure 1-1). OPHA is part of the Army's Moffett Community Housing (Community Housing) and was at one time, part of Moffett (Figure 1-2). The Navy transferred the Community Housing to the Air Force in 1994. The Community Housing was subsequently transferred to the Army in July 2000.

This Report was prepared on behalf of the Navy's Base Realignment and Closure Program Management Office West. This work was conducted under Contract Task Order No. 0079, issued under Remedial Action Contract No. N68711-98-D-5713.

### **1.1 SITE DESCRIPTION**

OPHA consists of housing units and support facilities along with associated streets, parking areas, and green space. Multi-family residences currently occupy most of OPHA. The area is relatively flat, ranging from 15 feet to 36 feet above mean sea level (msl). There are no wetlands or surface water located in OPHA. Stevens Creek is located due west of OPHA.

The area that is now OPHA was vacant or used for agriculture prior to the construction of military housing. Housing was constructed between the years 1941 through 1982 (Figure 1-3). The housing units include Moffett Homes built in 1941 (Figure 1-4), Orion Park built in 1968, and Macon Terrace II and Macon Terrace III built in 1982 (Foster Wheeler Environmental Corporation [FWENC], 2002a). The northern and southern rows of Moffett Homes were demolished in 1981 or 1982 to make room for Macon Terrace II and III construction. The remaining Moffett Homes units were demolished in 2001. The area that had been Moffett Homes is now open green space.

A portion of OPHA was used for agriculture until some time after 1965 (FWENC, 2002a). The approximate location of former farm buildings is shown on Figure 1-4. The former farm apparently had at least one potable supply well. Santa Clara Valley Water District (SCVWD) well records indicate that well 06S02W15G01, approximately 160 feet deep, was

decommissioned on March 24, 1993. The well was located immediately north of Housing Unit 842. The farmhouse likely had a septic tank and drain lines. Usage by normal household activities would not suggest VOC contamination (Air Force Base Conversion Agency, 2000). However, the U.S. Environmental Protection Agency (EPA) reports that organic solvents (including trichloroethene [TCE]) were one of three types of commonly used septic system cleaners (EPA, 2000).

## **1.2 PREVIOUS INVESTIGATIONS**

Investigations of OPHA and surrounding area were previously conducted to characterize the nature and extent of contaminated groundwater. The following information was reviewed prior to implementing the 2005 investigation:

- National Aeronautics and Space Administration (NASA) – Report of TCE in groundwater at the downgradient boundary of OPHA (Science Applications International Corporation [SAIC], 1999)
- Navy – Groundwater sample collection based on the information provided by NASA in 1999 (International Technology Corporation [IT], 2000)
- Navy – Phase 1 and 2 investigations to characterize the site, and to conduct a baseline risk assessment (FWENC, 2003)
- Army – Investigation of groundwater south (upgradient) and west of OPHA (The SI Group [SIG], 2003)
- EPA – Investigation of groundwater south (upgradient) of OPHA (EPA, 2005)

In 1999, NASA reported detections of TCE in groundwater samples near the northern (downgradient) boundary of OPHA (SAIC, 1999). The Navy collected groundwater samples along the south and west boundary of OPHA in 2000 (IT, 2000). TCE was detected in groundwater along the upgradient boundary and downgradient boundary of OPHA at similar concentrations (FWENC, 2002a). Previous investigation sampling locations are shown on Figure 1-5.

The Navy completed a two-phased site characterization program in 2002 to evaluate the nature and extent of groundwater VOC contamination, and to collect data needed to conduct a baseline human health risk assessment (FWENC, 2003). Phase 1 and Phase 2 field activities were conducted at OPHA and the Wescoat Housing Area. The Wescoat Housing Area is located immediately southeast of OPHA (see Figure 1-2). Only site characterization data collected from OPHA and the western portion of the Wescoat Housing Area are included this Report.

Phase 1 and Phase 2 site characterization-related field activities are described in the following sections. The Army and EPA conducted two separate off-site investigations upgradient of OPHA. These investigations are also described in the following sections.

### **1.2.1 Phase 1 Activities**

Phase 1 was implemented from February 27 through March 12, 2002. The purpose of Phase 1 groundwater sampling was to identify the extent of VOC contamination in the shallow groundwater at OPHA. The Phase 1 groundwater samples were collected from wells temporarily installed in the holes made by direct push technology (DPT) equipment and from DPT/HydroPunch® samples. DPT/temporary well groundwater samples were collected on a sample grid with nodes spaced on 300-foot centers in an attempt to locate potential VOC source areas. The purpose of the Phase 1 temporary well groundwater samples was to characterize the quality of the first-observed groundwater in the upper portion of the A aquifer (upper A aquifer). The purpose of Phase 1 cone penetrometer test (CPT) and DPT/HydroPunch® samples was to characterize the geology and quality of groundwater in the lower portion of the A aquifer (lower A aquifer). Phase 1 sample locations are shown on Figure 1-5.

#### **1.2.1.1 First-observed Groundwater Sampling**

Continuous soil cores, from 5 feet below ground surface (bgs) to first-observed groundwater, were collected at 41 OPHA locations (FW01A through FW41A) (see Figure 1-5). Cores were collected using a limited access DPT rig to push a nominal 2-inch-diameter, 4-foot-long, core barrel to the depth of first-observed groundwater. Cores were collected until saturated soil was observed. The geologic logs are included as Appendix A. Soil core samples were field-screened for organic vapor at 1-foot intervals. Field screening results were recorded on the geologic logs (Appendix A). Photoionization detector (PID) field screening organic vapor results for samples at 40 of 41 OPHA locations were between 0.0 and 3.0 parts per million (ppm). PID results between 9.2 and 3,500 ppm were detected from 5 to 13 feet bgs at FW41A.

Samples of first-observed groundwater were collected from wells temporarily installed in the holes made by the DPT soil core barrel. The DPT/temporary wells consisted of a 5-foot length of ¾-inch-diameter, polyvinyl chloride (PVC), 0.010-inch slotted screen and casing. DPT/temporary wells were sampled using a nominal ½-inch-diameter disposable Teflon bailer. Samples were collected within 30 minutes of well installation. Groundwater samples were analyzed for VOCs using EPA Method 8260B. Analytical results are included in Appendix A, Table A.1-1. The temporary wells were removed after sample collection and backfilled with a bentonite-cement grout.

#### **1.2.1.2 Lower A Aquifer Groundwater CPT and DPT/HydroPunch® Sampling**

Groundwater samples were collected from the lower A aquifer at seven OPHA DPT/temporary well sample locations (FW06A, FW07A, FW15A, FW24A, FW33A, FW34A, and FW41A). The samples were collected using a CPT rig and DPT/HydroPunch® sampling equipment as follows:

- An initial boring was advanced to 55 feet bgs using CPT equipment, producing a geologic log (CPT geologic logs are included in Appendix A).
- The geologic information was used to select a depth-specific groundwater sampling interval.
- A second boring, located about 4 feet away from the initial CPT boring, was advanced using DPT equipment and a HydroPunch® to collect the depth-specific groundwater sample.
- The HydroPunch® was advanced to the desired depth using DPT equipment. The HydroPunch® screen, 1 to 2 feet in length, was left open to the formation for a minimum of 15 minutes to allow groundwater to enter the screen.
- Groundwater samples were collected from the HydroPunch® using a disposable Teflon™ bailer.

Samples collected using the above procedure are referred to as DPT/HydroPunch® samples. The sample locations are referred to as CPT and DPT/ HydroPunch® sample locations.

Samples were collected at locations along the southern (upgradient) OPHA boundary (see Figure 1-5). Samples were analyzed for VOCs using EPA Method 8260B. Analytical results are included in Appendix A, Table A.1-1. Phase 1 geologic data are included in the geology and hydrogeology description of Section 5.0. Phase 1 VOC data are included in the contaminant distribution and migration description in Section 6.0.

### **1.2.2 Phase 2 Activities**

Phase 2 sampling activities were conducted between August 28 and September 26, 2002. The purpose of Phase 2 soil core field screening, soil sampling, and first-observed groundwater DPT/temporary well sampling was primarily for baseline human health risk assessment purposes. Results of the baseline human health risk assessment are presented in the *Final Site Characterization and Baseline Human Health Risk Assessment Report* (FWENC, 2003). However, since these data also provide VOC contaminant distribution information and geotechnical information, they are presented herein. The purpose of Phase 2 CPT and DPT/HydroPunch® sampling was to evaluate the distribution of VOC contaminants in permeable layers throughout the upper and lower portions of the A aquifer. Phase 2 DPT/temporary well, CPT and DPT/HydroPunch® sample locations are shown on Figure 1-5.

#### **1.2.2.1 Soil and First-observed Groundwater Sampling**

Continuous soil cores from 5 feet bgs to first-observed groundwater were collected at five OPHA locations (FW03B through FW07B). Field screening results for organic vapors were between zero and 2.9 ppm as measured by a MiniRAE PID. Results were recorded on the geologic logs. The geologic logs are included in Appendix A. A maximum of three lithologic types were identified in the unsaturated zone at each location. Soil samples were analyzed for percent



organic carbon by the Walkley-Black method, and for bulk density, specific gravity, and percent moisture using American Society for Testing and Materials (ASTM) Methods D2937, D854, and D2216, respectively. Analytical results are included in Appendix A, Table A.1-2.

Groundwater samples were collected from each DPT/temporary well location (FW01B through FW07B) as described in Section 1.2.1. Groundwater samples were analyzed for VOCs using EPA Method 8260B. Groundwater analytical results are included in Appendix A, Table A.1-3.

#### **1.2.2.2 A Aquifer Groundwater CPT and DPT/HydroPunch® Sampling**

Phase 2 activities included sampling 20 additional locations (FW8B through FW27B) using a CPT rig and DPT/HydroPunch® equipment, as described in Section 1.2.1.2. The CPT geologic logs were used to identify up to five potential water-bearing zones at each location. CPT geologic logs are included in Appendix A. Samples were analyzed for VOCs using EPA Method 8260B. Analytical results are included in Appendix A, Table A.1-3. Phase 2 CPT and DPT/HydroPunch® sample locations are shown on Figure 1-5. Phase 2 geologic data are presented in the geology and hydrogeology description in Section 5.0. Phase 2 VOC data are discussed in the contaminant distribution and migration description in Section 6.0.

#### **1.2.3 Army Off-site Investigation**

The Army completed an off-site investigation south and west of OPHA in September 2003 (SIG, 2003). The investigation included collecting groundwater samples at 19 locations (SIG1 through SIG19) using a CPT rig and DPT/HydroPunch® equipment. Army sample locations are shown on Figure 1-5. Groundwater samples were collected similarly to the method previously described in Section 1.2.1.2, except the Army used a 5-foot screen interval. Army CPT geologic logs are included in Appendix A. Groundwater samples were analyzed for VOCs using EPA Method 8260B. Analytical results are included in Appendix A, Table A.1-4. Army geologic data are included in the geology and hydrogeology description of Section 5.0. Army VOC data are included in the contaminant distribution and migration description of Section 6.0.

#### **1.2.4 EPA Off-site Investigation**

The EPA completed an off-site investigation in September 2005 (EPA, 2005). The investigation included collecting groundwater samples at 20 locations (HP 01 through HP 20) using a CPT rig and DPT/HydroPunch® equipment. Samples were collected primarily south (upgradient) of the Army's area of investigation, south of the Highway 101/Moffett Boulevard interchange. EPA sample locations are shown on Figure 1-5. EPA CPT geologic logs are included in Appendix A.

EPA groundwater samples were analyzed for VOCs using EPA Method 524.2. All Navy and Army groundwater samples were analyzed for VOCs using EPA Method 8260B. EPA Method 8260B is a hazardous waste method. EPA Method 524.2 is a drinking water method and is typically used to detect low levels of contamination. EPA Method 524.2 is designed for samples

with low matrix interference, is not typically used to evaluate contaminated groundwater, and is not appropriate for samples with high sediment content (such as samples collected using HydroPunch<sup>®</sup> equipment) and high VOC concentrations (EPA, 2004a; 1995). Analytical results are included in Appendix A, Table A.1-5. EPA geologic data are included in the geology and hydrogeology description in Section 5.0. EPA VOC data are included in the contaminant distribution and migration description in Section 6.0.

### 1.3 PROJECT OBJECTIVES

VOCs were detected in the groundwater upgradient, beneath, and downgradient of OPHA during previous investigations. On-site sources of the groundwater contamination underlying OPHA had not been identified. Based on the observed groundwater contaminant distribution, contamination appeared to originate off-site. Since monitoring wells had not been constructed at OPHA, groundwater flow direction(s) were projected from the other areas of Moffett. Time-dependent groundwater samples representative of the upper and lower portion of the A aquifer had not been collected or evaluated. The original objectives identified in the *Final Groundwater Monitoring Well Installation and Sampling Work Plan for Orion Park Housing Area* (Tetra Tech FW, Inc.[TtFW], 2005) included the following:

- Install 11 groundwater monitoring wells
- Complete two rounds of groundwater gauging and sampling
- Evaluate groundwater flow directions
- Evaluate contaminant distribution in the upper and lower portions of the A aquifer
- Evaluate the potential for contaminants to migrate between the upper and lower portions of the A aquifer

Subsequently, two additional rounds of groundwater gauging and sampling were accomplished to achieve a total of four quarters of groundwater sampling. The objective of collecting four quarters of groundwater data was to evaluate possible water level and chemical trends.

### 1.4 REPORT ORGANIZATION

This report is organized as follows:

- **Section 1.0** presents OPHA site description and history, a summary of previous investigations, project objectives, and report organization.
- **Section 2.0** presents the groundwater monitoring well installation, sampling and gauging field activities
- **Section 3.0** presents the on-site analytical sample results and discusses the Army and EPA off-site results
- **Section 4.0** presents the sample quality assurance and quality control

- **Section 5.0** presents the geology and hydrogeology
- **Section 6.0** presents an evaluation of contaminant distribution and migration, an evaluation of trends, and a conceptual site model
- **Section 7.0** is a summary
- **Section 8.0** is a list of references
- **Tables and Figures** follow the text
- **Appendix A** includes geologic logs and geochemical data from previous investigations on compact disk only
- **Appendix B** includes well permits, geologic and well construction logs, and well development logs
- **Appendix C** includes the well location survey report on compact disk only
- **Appendix D** includes the low-flow groundwater sampling data sheets on compact disk only
- **Appendix E** includes analytical results and chain-of-custody documentation on compact disk only
- **Appendix F** includes stable isotope study analysis
- **Appendix G** includes University of Waterloo Laboratory Protocols for Stable Isotope Analysis

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## **2.0 FIELD ACTIVITIES**

This section provides a summary of the activities associated with groundwater monitoring well installation, gauging, and sampling.

### **2.1 WELL INSTALLATION AND SAMPLING ACTIVITIES**

Monitoring well installation, gauging, and sampling activities included the following tasks:

- Geophysical surveying to identify subsurface utilities
- Drilling using a hollow-stem auger rig and collecting continuous soil cores
- Field screening the soil core for total VOCs using a PID
- Logging the soil core by a field geologist
- Constructing monitoring wells
- Developing monitoring wells
- Surveying locations and elevations of newly constructed monitoring wells
- Gauging and sampling monitoring wells
- Characterizing, transporting, and disposing of waste, including soil investigation-derived waste (IDW) at approved landfills and processing wastewater through the West-Side Aquifers Treatment System (WATS)
- Site restoration

### **2.2 GROUNDWATER MONITORING WELL LOCATION SELECTION**

Eleven monitoring wells were installed between July 11, and July 21, 2005. Six wells, MCH-1UA, MCH-3UA, MCH-5UA, MCH-7UA, MCH-9UA, and MCH-11UA, were screened in the upper portion of the A aquifer (Figure 2-1). Five wells, MCH-2LA, MCH-4LA, MCH-6LA, MCH-8LA, and MCH-10LA, were screened in the lower portion of the A aquifer (see Figure 2-1). Well installation included two monitoring well pairs (MCH-1UA/MCH-2LA and MCH-7UA/MCH-8LA) constructed in the upper and lower portion of the A aquifer. The monitoring well locations were selected to evaluate local groundwater flow direction(s) and to evaluate the extent of the TCE in the A aquifer. The location selected for each well or well pair is as follows:

- MCH-1UA – Located near the upgradient (southern) OPHA boundary in the upper portion of the A aquifer. MCH-1UA is located near Phase 1 and 2 sample location FW41A/FW12B (see Figure 2-1), where VOC vapors were detected with a PID at a maximum concentration of 3,500 ppm during Phase 1 soil core field screening, and elevated TCE concentrations (290 micrograms per liter [ $\mu\text{g/L}$ ]) were detected in

HydroPunch<sup>®</sup> groundwater samples collected in the upper A aquifer. MCH-1UA is part of an upper/lower A aquifer well pair with MCH-2LA.

- MCH-2LA – Located near the upgradient OPHA boundary in the lower portion of the A aquifer. MCH-2LA is located near Phase 1 and 2 sample location FW41A/FW12B (see Figure 2-1), where elevated TCE concentrations (410 µg/L) were detected in HydroPunch<sup>®</sup> groundwater samples collected in the lower A aquifer. MCH-2LA is part of an upper/lower A aquifer well pair with MCH-1UA, and is located 5 feet west of MCH-1UA.
- MCH-3UA – Located near the middle of the upgradient OPHA boundary in the upper portion of the A aquifer. MCH-3UA is located near Army off-site sample location SIG6 (within the Highway 101/Moffett Boulevard interchange, see Figure 2-1), where an elevated TCE concentration (230 µg/L) was detected in a HydroPunch<sup>®</sup> groundwater sample collected in the upper A aquifer (SIG, 2003).
- MCH-4LA – Located near the middle of the southern OPHA boundary in the lower portion of the A aquifer. MCH-4LA is located approximately 125 feet northeast of Army off-site sample location SIG5 (within the Highway 101/Moffett Boulevard interchange, see Figure 2-1), where an elevated TCE concentration (870 µg/L) was detected in a HydroPunch<sup>®</sup> groundwater sample collected in the lower A aquifer (SIG, 2003).
- MCH-5UA – Located near the eastern OPHA boundary in the area of Phase 2 sample location FW15B (see Figure 2-1), where an elevated TCE concentration (210 µg/L) was detected in a HydroPunch<sup>®</sup> groundwater sample collected in the upper A aquifer.
- MCH-6LA – Located near the western OPHA boundary in the area of Phase 2 sample location FW17B (see Figure 2-1), where an elevated TCE concentration (1,100 µg/L) was detected in a HydroPunch<sup>®</sup> groundwater sample collected in the lower A aquifer.
- MCH-7UA – Located in the area of Phase 1 and 2 sample locations FW30A and FW04B (see Figure 2-1), where elevated TCE concentrations (320 µg/L and 250 µg/L, respectively) were detected in HydroPunch<sup>®</sup> groundwater samples collected in the upper A aquifer. MCH-7UA is part of an upper/lower A aquifer well pair with MCH-8LA.
- MCH-8LA – Located near Phase 2 sample location FW20B (see Figure 2-1), where an elevated TCE concentration (700 µg/L) was detected in a HydroPunch<sup>®</sup> groundwater sample collected in the Lower A aquifer. MCH-8LA is part of an upper/lower A aquifer well pair with MCH-7UA, and is located 12 feet east of MCH-7UA.
- MCH-9UA – Located near the western OPHA boundary in the area of Phase 1 sample location FW35A (see Figure 2-1), where an elevated TCE concentration (350 µg/L) was detected in a HydroPunch<sup>®</sup> groundwater sample collected in the upper A aquifer.
- MCH-10LA – Located in the north central portion of OPHA in the area of Phase 2 sample location FW18B (see Figure 2-1), where an elevated TCE concentration (740

µg/L) was detected in a HydroPunch® groundwater sample collected in the lower A aquifer.

- MCH-11UA – Located hydraulically downgradient from the former farm buildings in the upper A aquifer. The location for MCH-11UA was selected after wells MCH-1UA, MCH-3UA, MCH-5UA, MCH-7UA were installed and gauged to determine the local hydraulic gradient/flow direction.

Monitoring well locations were selected and approved by the EPA and the California Regional Water Quality Control Board (Water Board), with concurrence from NASA during a site walk on April 6, 2005.

### **2.3 MONITORING WELL BOREHOLE DRILLING**

Santa Clara Valley Water District well construction applications were executed prior to monitoring well construction. The well construction applications are included in Appendix B. Underground Service Alert was notified and a geophysical survey was performed at each proposed monitoring well location before drilling. Each location was cleared for underground utilities by hand-augering to 5 feet bgs.

Borings for monitoring wells were drilled using a hollow-stem auger drill rig equipped with nominal 10-inch-outside-diameter hollow-stem augers. Borings were advanced to a maximum depth of 29 feet bgs for upper A aquifer monitoring wells or 54 feet bgs for lower A aquifer monitoring wells. Borings were cored continuously using either an 18-inch-long, nominal 2-inch-diameter or a 5-foot-long, nominal 4-inch-diameter split-barrel sampler. At upper and lower A aquifer well pair locations, only the deeper boring was logged for both the upper and lower A aquifer.

### **2.4 FIELD SCREENING AND LITHOLOGIC LOGGING**

The soil cores collected from the unsaturated zone were screened for VOCs using a PID. The core barrels were opened and placed on the logging table. The PID was moved along the length of the open core at a distance of about 6 inches above the core. VOCs were not detected in the soil cores. Therefore, soil samples for chemical analyses were not collected. (Soil samples were to be collected for laboratory analysis if VOC concentrations greater than 500 ppm were detected with a PID during field screening.)

The soil cores were then logged by, or under the supervision of, a California Professional Geologist in accordance with the Unified Soils Classification System (USCS), as described in *Visual Classification of Soil, Unified Soil Classification System* (Bureau of Reclamation, 1986), ASTM D2488-00 (2000), and the Munsell® soil chart (GretagMacbeth, 1994) for color designation. The logs are included in Appendix B.

Heaving sand conditions (a sand/groundwater mixture that enters the augers because of reduced pressure within the augers) were observed below the water table at several locations. Heaving sand conditions resulted in difficulties collecting intact core samples. Cores were often full of the sand/groundwater mixtures (slough) that had entered the augers and were described as “potential slough” on the logs. As a result, sand may have been overlogged and sand thickness overestimated at some locations. Locations where sand thickness may have been overestimated because of heaving sands (indicted by “poor recovery” or “potential slough” on continuous core logs) were the following:

- MCH-2LA from 14 to 24 feet bgs
- MCH-2LA from 30 to 44 feet bgs
- MCH-8LA from 21 to 29 feet bgs
- MCH-10LA from 21.5 to 24 feet bgs

## **2.5 MONITORING WELL CONSTRUCTION**

The monitoring wells were constructed inside the hollow-stem augers. Each monitoring well was constructed of nominal 4-inch-diameter, flush-threaded, schedule 40 PVC casing, and a 0.010-inch slotted, wire-wrapped, PVC screen. The continuous soil core information was used to aid in selecting the monitoring well screen length and placement. The upper A aquifer wells were completed to a maximum depth of 26 feet bgs. The lower A aquifer wells were completed to a maximum depth of 54 feet bgs. All well screens were 10 feet in length.

Well screens were placed across the thickest permeable layer or layers observed during the continuous coring and logging process. The middle of the screen interval generally was placed across the middle of the permeable layer or layers. Centralizers were installed at the top and bottom of the well screen. The filter pack consisted of clean silica sand (No. 2/12), and was placed from the bottom of the screen interval to approximately 2 feet above the top of the screened interval. The filter pack material was tremied or slowly poured from ground surface into the annular space as the augers were withdrawn. The monitoring wells were surged during filter pack installation to ensure settlement of the filter material.

A bentonite transitional seal, at least 2 feet thick, was placed on top of the filter pack. The bentonite transitional seal was composed of Wyo-Ben Hydrogel<sup>®</sup> granular bentonite. The bentonite transitional seal material was tremied or slowly poured from ground surface into the annular space in 1-foot lifts. Potable water was added to hydrate the bentonite transitional seal placed above the local groundwater level. The total bentonite transitional seal was allowed to hydrate for a minimum of 1 hour before the annular seal material was placed. The annular seal consists of a bentonite-cement grout (3 to 5 percent bentonite by dry weight) tremied in place from the top of the bentonite transitional seal to approximately 2 feet bgs.



Monitoring wells MCH-3UA, -4LA, -5UA, -6LA, -7UA, -8LA, -9UA, and -11UA were installed within grassy or landscaped areas with aboveground surface completions. Monitoring wells MCH-1UA, -2LA, and -10LA were installed within grassy or landscaped areas with flush-mount surface completions. Monitoring well construction details are included on the boring logs provided in Appendix B. All downhole equipment was cleaned before the first use and before use at each new location using a hot water pressure washer.

## **2.6 MONITORING WELL DEVELOPMENT**

The monitoring wells were developed between August 2 and August 4, 2005. The monitoring wells were initially bailed to clean out any sediment accumulated at the bottom of the well using a bottom-suction bailer. Then the well screen interval was surged with a surge block. Accumulated sediment was removed by bailer. Finally, a submersible pump was installed just above the screen interval and the well was pumped until the field parameters stabilized, as follows:

- No visible change in the appearance of discharge water, or turbidity stabilized to less than 50 nephelometric turbidity units
- Temperature was within  $\pm 1$  degree Celsius for consecutive readings
- Conductivity was within  $\pm 5$  percent micromhos per centimeter for consecutive readings
- Hydrogen ion concentration (pH) was within  $\pm 0.2$  units for consecutive readings

The pump was lowered through the screened interval, allowing stabilization of the field parameters as the pump was lowered.

All equipment was decontaminated prior to use. All water parameter data and approximate volumes of water produced were reported on the well development form. Field instruments for measurement of water parameters, including temperature, pH, and specific conductance, were calibrated daily, according to manufacturer specifications prior to use. Well development logs for the new monitoring wells are provided in Appendix B.

## **2.7 SURVEYING**

The ground surface adjacent to the monitoring well and top of well casing vertical elevations were surveyed. The north side of the well casing is the elevation reference point and was marked with a minimum 1/8-inch-deep sawcut. The horizontal locations were also surveyed. The survey was conducted using a third-order, Class 1 accuracy established by current Federal Geodetic Control Subcommittee standards for both vertical and horizontal measurements (at least within  $\pm 0.1$  foot accuracy for horizontal measurements and  $\pm 0.01$  foot accuracy for vertical measurements). Horizontal control was tied to the State Plane Coordinate System, based on the North American Datum (NAD) of 1983 as feet northing and easting. Vertical control was tied to

the North American Vertical Datum of 1988 and given in feet of elevation above msl. The surveyor also reported all horizontal data in NAD 1927 (feet) and elevations as National Geodetic Vertical Datum 1929 (feet msl). A monitoring well survey report generated and signed by a state of California-registered Professional Land Surveyor is provided in Appendix C.

## **2.8 GROUNDWATER GAUGING**

Groundwater gauging of monitoring wells MCH-1UA, -3UA, -5UA, and -7UA was conducted on July 15, 2005. Gauging results were used to calculate the local groundwater flow direction in the area of the former farm buildings. Monitoring well MCH-11UA was located hydraulically downgradient from the former farm buildings. The depth to groundwater level measurements were converted to msl and contoured with Surfer<sup>®</sup> using the nearest neighbor method. The preliminary interpretation suggested a north-northwest groundwater flow. As a result, monitoring well MCH-11UA was placed between housing units 716 and 727.

Groundwater gauging of all OPHA groundwater monitoring wells and three wells located east of OPHA (87B1, W89-6, and W89-7) (see Figure 2-1) was completed during each sampling event and the regional Moffett Black Thursday event, as follows:

- August 8, 2005 (first sampling event)
- November 17, 2005 (Black Thursday event)
- December 7, 2005 (second sampling event)
- March 21, 2006 (third sampling event)
- June 12, 2006 (fourth sampling event)

Depth to groundwater was measured to the nearest 0.01 foot. Well gauging data were recorded on the low-flow groundwater sampling data sheets included in Appendix D. Upper and lower A aquifer groundwater potentiometric surface maps for the August and November 2005, and the March 2006 gauging event and water level trend plots are presented in Section 5.0.

## **2.9 MONITORING WELL SAMPLING**

Four rounds of groundwater samples were collected. Wells sampled included the 11 new wells installed at OPHA and three existing wells (87B1, W89-6, and W89-7) located east of OPHA on NASA property. The first groundwater sampling event took place August 8 and 9, 2005. The second groundwater sampling event took place December 8 and 9, 2005. The third groundwater sampling event took place March 21 and 22, 2006. The fourth groundwater sampling event took place June 13 and 14, 2006.

A peristaltic pump was used for purging and sampling. Wells were purged by slowly lowering new high-density polyethylene (HDPE) tubing into the well to the midpoint of the screen interval, attaching the HDPE tubing to a peristaltic pump, and pumping at a low flow rate of

approximately 0.2 to 0.5 liters per minute (L/min). During purging, pH, temperature, turbidity, specific electrical conductance, oxidation-reduction potential, and dissolved oxygen were monitored approximately every 3 to 5 minutes. Purging continued until indicator parameters stabilized. Flow rates were reduced to between 0.1 and 0.2 L/min prior to filling volatile organic analysis vials. Low-flow groundwater sampling data sheets are provided in Appendix D.

## **2.10 IDW DISPOSAL**

Soil cores were deposited in Department of Transportation (DOT)-approved 55-gallon drums after logging was completed. The drums of soil were disposed of as IDW. Forty-four drums of soil were transported as non-hazardous waste by DenBeste, Inc. and disposed of at Altamont Landfill on December 20, 2005. Decontamination liquids, well development water, and well purge water were temporarily stored in DOT-approved 55-gallon drums and disposed of through WATS.

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### **3.0 GROUNDWATER MONITORING WELL SAMPLE ANALYTICAL RESULTS**

Fourteen groundwater monitoring wells were sampled in August 2005, December 2005, March 2006, and June 2006. Sampled wells included the 11 newly installed OPHA wells and three existing wells located east of OPHA on NASA property. This section provides a summary of the groundwater monitoring well sample analytical results. Groundwater samples were analyzed for VOCs using EPA Method 8260B (purge and trap) for all four sampling events. In addition, for the first two sampling events, groundwater samples were analyzed for major anions and cations by EPA Methods 6010B and 300.0, respectively, and for chlorine and carbon stable isotope ratios by gas chromatography/isotope ratio mass spectrometry (GC/IRMS). Advances in instrumentation and methodology plus subsequent research has shown that for VOCs, standard purge and trap units coupled to GC/IRMS instruments can generate accurate isotope results. Soil samples for chemical analysis were not collected during this project because VOCs were not detected in soil cores during field screening with a PID.

Groundwater samples for VOC, anion, and cation analysis were shipped to EMAX Laboratory, which is certified by the California Department of Health Services for the required analytical methods. EMAX Laboratory has successfully completed the Naval Facilities Engineering Service Center Laboratory Evaluation Program. Groundwater samples for isotope ratio analysis were shipped to the University of Waterloo in Ontario, Canada. Laboratory analytical results and chain-of-custody documentation are provided in Appendix E. The University of Waterloo protocols for stable isotope analysis are provided in Appendix G.

#### **3.1 VOC ANALYTICAL RESULTS**

Monitoring well groundwater samples collected during all four rounds of sampling were analyzed for VOCs using EPA Method 8260B. Analytical results were used to complete the project objective of evaluating contaminant distribution in the upper and lower portions of the A aquifer. VOC analytical results are described in the following sections. Monitoring well analytical results are combined with previous on- and off-site VOC data in Section 6.0 to present a comprehensive VOC trend and distribution evaluation.

##### **3.1.1 August 2005**

August 2005, VOC analytical results are presented in Table 3-1. Groundwater monitoring well samples contained TCE and its breakdown products cis-1,2-dichloroethene (cis-1,2-DCE), trans-1,2-dichloroethene (trans-1,2-DCE), 1,1-dichloroethene (1,1-DCE), and vinyl chloride (VC). TCE concentrations ranged from an estimate of 3 µg/L at MCH-8LA to 1,200 µg/L at MCH-10LA. Cis-1,2-DCE concentrations ranged from not detected at a laboratory reporting limit of 5 µg/L in the sample collected from MCH-8LA to 370 µg/L in the sample collected from MCH-

2LA. The VOC compounds trans-1,2-DCE, 1,1-DCE, and VC were detected with less frequency and at lower concentrations than TCE and cis-1,2-DCE, with one exception - VC was detected in the sample collected from off-site upper A aquifer well W89-6 at a concentration of 110 µg/L. VC was primarily detected in samples from groundwater monitoring wells MCH-1UA and MCH-2LA underlying OPHA.

### **3.1.2 December 2005**

December 2005 VOC analytical results are presented in Table 3-2. Generally, December 2005 VOC concentrations were similar to those detected in August 2005. A few of the monitoring well samples showed an increase in TCE concentration. TCE concentrations ranged from not detected at a laboratory reporting limit of 5 µg/L in the sample collected from MCH-8LA, to 1,100 µg/L in the sample collected from MCH-10LA. A few of the monitoring well samples showed an increase in cis-1,2-DCE concentration. Cis-1,2-DCE concentrations ranged from not detected at a laboratory reporting limit of 5 µg/L in the sample collected from MCH-8LA to 490 µg/L in the sample collected from MCH-2LA. A few of the monitoring well samples showed an increase in VC concentration. An increase in the concentration of VC from 110 µg/L in August 2005, to 330 µg/L in December 2005, was observed in the sample collected from off-site upper A aquifer monitoring well W89-6. VC was primarily detected in samples from groundwater monitoring wells MCH-1UA and MCH-2LA underlying OPHA. The VOC compounds trans-1,2-DCE and 1,1-DCE were generally detected with less frequency and at lower concentrations than TCE and cis-1,2-DCE.

### **3.1.3 March 2006**

March 2006 VOC analytical results are presented in Table 3-3. Generally, March 2006 VOC concentrations were less than those detected in December and August 2005. There was a significant decrease in TCE concentration in the groundwater sample from well MCH-10LA - from 1,100 µg/L in December 2005 to 71 µg/L in March 2006, but the March results appear to be anomalous as the November and December 2005 and June 2006 results were at higher concentrations (see Sections 3.1.1, 3.1.2, and 3.1.4). TCE concentrations ranged from not detected at a laboratory reporting limit of 5 µg/L in the sample collected from well W89-7 to 390 µg/L in the sample collected from well MCH-6LA. Cis-1,2-DCE concentrations ranged from not detected at a laboratory reporting limit of 5 µg/L in the samples collected from wells MCH-8LA and W89-7 to 380 µg/L in the sample collected from well MCH-2LA. VC was primarily detected in samples from groundwater monitoring wells MCH-1UA and MCH-2LA underlying OPHA. The VOC compounds trans-1,2-DCE and 1,1-DCE were generally detected with less frequency and at lower concentrations than TCE and cis-1,2-DCE.

### **3.1.4 June 2006**

June 2006 VOC analytical results are presented in Table 3-4. Generally, June 2006 VOC concentrations were similar to those detected in August 2005. TCE concentrations ranged from

not detected at a laboratory reporting limit of 5 µg/L in samples collected from wells MCH-8LA, W89-6, and W89-7 to 870 µg/L in the sample collected from MCH-10LA. Cis-1,2-DCE concentrations ranged from not detected at a laboratory reporting limit of 5 µg/L in the sample collected from well W89-7 to 320 µg/L in the sample collected from well MCH-2LA. VC was primarily detected in samples from groundwater monitoring wells MCH-1UA and MCH-2LA underlying OPHA. The VOC compounds trans-1,2-DCE and 1,1-DCE were generally detected with less frequency and at lower concentrations than TCE and cis-1,2-DCE.

### **3.2 ANION AND CATION ANALYTICAL RESULTS**

Data for major cations (calcium, sodium, magnesium, and potassium) and anions (bicarbonate, carbonate, chloride, nitrate/nitrite-N, and sulfate) were collected in order to determine whether there is any geochemical difference between the two water-bearing zones. An evaluation of major cation and anion data is presented in Section 5.6.

#### **3.2.1 August 2005**

August 2005 anion and cation analytical results are presented in Table 3-5. Three of four major cations (calcium, magnesium, and sodium) analyzed were detected in groundwater during August 2005. Potassium was not detected in any samples. Calcium yielded the highest concentrations ranging from 112 milligrams per liter (mg/L) in MCH-9UA to 223 mg/L in W89-7. Magnesium and sodium were detected at lower concentrations ranging from 39.6 to 91.6 mg/L and 32.3 to 50.2 mg/L, respectively.

Major anions detected in groundwater included bicarbonate alkalinity, chloride, nitrate/nitrite-N, and sulfate. Carbonate alkalinity was not detected in any samples. Bicarbonate yielded the highest concentrations ranging from 269 mg/L in MCH-8LA to 680 mg/L in W89-7. Chloride, nitrate/nitrite-N, and sulfate were detected at lower concentrations ranging from 28.6 to 39.3 mg/L, 0.111 to 1.85 mg/L, and 138 to 273 mg/L, respectively.

#### **3.2.2 December 2005**

December 2005 anion and cation analytical results are presented in Table 3-6. All four major cations (calcium, magnesium, potassium, and sodium) were detected in December 2005. Calcium concentrations ranged from 75 mg/L in W89-6 to 179 mg/L in W89-7. Magnesium, potassium, and sodium were detected at concentrations ranging from 38.4 to 75.1 mg/L, 1.2 to 2.2 mg/L, and 32.4 to 44.0 mg/L, respectively.

Major anions detected in groundwater included bicarbonate alkalinity, chloride, nitrate/nitrite-N, and sulfate. As in August 2005, carbonate alkalinity was not detected in any samples. Bicarbonate yielded the highest concentrations ranging from 285 mg/L in MCH-8LA to 472 mg/L in W89-7. Chloride, nitrate/nitrite-N, and sulfate were detected at lower concentrations ranging from 29.2 to 37.2 mg/L, 0.197 to 1.76 mg/L, and 113 to 283 mg/L, respectively.

Compared to the results for August 2005, concentrations of major cations and anions in groundwater in December 2005 showed minimal difference. Well W89-7 typically showed higher concentrations of cations and anions compared to the other wells. In addition, there was no notable difference in results between wells screened in the upper and lower portion of the A aquifer.

### **3.3 STABLE ISOTOPE ANALYTICAL RESULTS**

The primary objective of the stable isotope study was to evaluate and determine if the TCE beneath OPHA originated from off-site and/or on-site source(s). It is believed that this objective can be achieved using multiple lines of evidence, including an understanding of site-specific hydrogeology and geochemistry (including isotopic composition). Results of the stable isotope study are summarized in Section 6.0. A detailed description of the stable isotope study methodology and results are included in Appendix F.

#### **3.3.1 August 2005**

August 2005 analytical results are presented in Table 3-7. Isotope ratios for W89-6 and W89-7 were not determined because TCE was not detected in the groundwater samples collected at their location during August 2005. Only isotope ratios for chlorine could be determined for MCH-8LA, since the concentration of TCE in this sample was below the carbon quantitation level.

#### **3.3.2 December 2005**

December 2005 analytical results are presented in Table 3-8. Isotope ratios for MCH-8LA, W89-6 and W89-7 were not determined because TCE was not detected in the groundwater samples collected at these locations during December 2005.



## 4.0 QUALITY ASSURANCE AND QUALITY CONTROL

Water samples were analyzed by a California-certified and Navy-evaluated laboratory and by an isotope laboratory at University of Waterloo in Canada. A third-party validation company performed data validation of all samples, except for isotope data, which does not require validation. The validation was conducted in accordance with the EPA Contract Laboratory Program *National Functional Guidelines For Organic Data Review*, EPA 54D/R-99/008 (EPA, 1999), the Contract Laboratory Program *National Functional Guidelines for Inorganic Data Review*, EPA 54D/R-04/004 (EPA, 2004b), the Department of Defense (DoD) *Quality Systems Manual for Environmental Laboratories* (DoD, 2006), and the criteria specified in the *Final Groundwater Monitoring Well Installation and Sampling Work Plan for Orion Park OPHA Sampling and Analysis Plan* (TtFW, 2005). Twenty percent of the samples were validated in accordance with an EPA Level IV-equivalent protocol. The remainder of the samples were validated with EPA Level III-equivalent protocol. The chain-of-custody records, laboratory reports, and data validation reports are included in Appendix E.

### 4.1 FIELD QUALITY CONTROL SAMPLING OBJECTIVES

Field quality control (QC) sampling objectives were met per the *Final Groundwater Monitoring Well Installation and Sampling Work Plan for Orion Park OPHA Sampling and Analysis Plan* (TtFW, 2005). Three field duplicates, five trip blanks, and four matrix spike and matrix spike duplicates (MS/MSDs) were required and collected. The results of the field QC sampling are described in the following sections.

#### 4.1.1 Field Duplicates

Field duplicates were collected at a frequency of 1 per every 10 samples and were analyzed for the same parameters as the original sample. Field duplicate samples were collected from wells MCH-3UA, MCH-4LA, MCH-6LA, MCH-7UA, MCH-9UA, and 87B1. The relative percent difference (RPD) was greater than 25 percent for TCE and potassium for the field duplicate pair collected from MCH-6LA. However, the RPD cannot be calculated for potassium, which was detected in the method blank and is reported as not detected. The nitrate and nitrite RPD for the sample pair collected from MCH-3UA was also greater than 25 percent. With the exception of potassium in MCH-6LA, estimated value (J) qualifiers were required for affected compounds as a result of field duplicate RPDs being outside of QC limits.

#### **4.1.2 Trip Blanks**

The five trip blank samples 79-017, 79-033, 79-034, 079-52, and 079-070 were transported with the water samples to the laboratory and analyzed for VOCs. Toluene was detected in trip blank sample 079-017; however, samples were not qualified because toluene was not detected in the affected field samples.

#### **4.1.3 Matrix Spike and Matrix Spike Duplicate**

MS/MSD samples were collected at a frequency of one per every 20 samples. Groundwater samples from MCH-7UA, MCH-8LA, and W89-7 were selected for MS/MSD analysis. The percent recoveries and RPDs for the MS/MSD sample collected from MCH-7UA were outside the specified QC limits for compounds toluene, 1,1-DCE, benzene, and chlorobenzene. Affected compounds were not flagged, as qualifiers were not required for undetected analytes.

### **4.2 ANALYTICAL DATA QUALITY OBJECTIVES**

The following sections describe the fulfillment of the analytical data quality objectives, as described in the *Final Groundwater Monitoring Well Installation and Sampling Work Plan for Orion Park Housing Area Sampling and Analysis Plan* (TtFW, 2005).

#### **4.2.1 Holding Times**

All samples met the holding time.

#### **4.2.2 Method Blanks**

Methylene chloride, potassium, and sodium were detected at low levels in the method blanks from samples collected in August 2005. Calcium and magnesium were detected at low levels in the method blanks from samples collected in December 2005. Methylene chloride, calcium, magnesium, and sodium did not require qualifiers for either August or December samples, as associated sample results were either not detected or were significantly greater than the concentrations found in the associated method blanks. Potassium samples collected in August 2005, however, were flagged “U” (not detected at the laboratory reporting limit), as potassium in the associated samples was not detected at greater than 5 times the concentrations found in the associated method blank.

#### **4.2.3 Surrogate Percent Recovery**

Surrogate percent recoveries were outside QC limits for samples collected from MCH-8LA, MCH-10LA, and MCH-2LA in August 2005. However, the affected compounds from MCH-2LA and MCH-10LA reported in Table 3-1 were from the dilution analysis, where the surrogate percent recoveries were within the QC limits and therefore, did not require any qualifiers. For samples collected from MCH-8LA, “UJ” (not detected at the laboratory reporting limit, which was estimated) and/or “J” qualifiers were required for affected compounds.

#### **4.2.4 Laboratory Control Samples**

All laboratory control samples were within QC limits.

#### **4.2.5 Internal Standards**

All internal standard areas and retention times were within QC limits.

#### **4.2.6 Target Compound Identification**

All target analytes were correctly identified.

#### **4.2.7 Compound Quantitation**

Laboratory Data Consultants, Inc. evaluated compound quantitation during Level IV reviews. All sample result verifications were acceptable.

#### **4.2.8 System Performance**

System performance met all QC requirements. No discrepancies were reported.

#### **4.2.9 Completeness**

No samples were rejected from this project, which resulted in 100 percent completeness.

### **4.3 OVERALL ASSESSMENT OF DATA**

All groundwater data collected from OPHA are valid and usable. TCE, cis-1,2-DCE, and/or VC, were detected at high concentrations in some groundwater samples, requiring the samples to be diluted. The diluted results for TCE, cis-1,2-DCE, and VC are reported in this document. The remaining compounds are reported as undiluted results.

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## **5.0 GEOLOGY AND HYDROGEOLOGY**

This section provides an interpretation of the geologic and hydrogeologic conditions at OPHA using the geologic and geochemical data gathered during the recent monitoring well installation supplemented with Phase 1 and Phase 2 investigation data (TtFW, 2003), and Army (SIG, 2003) and EPA (2005) investigation data from south of Highway 101.

### **5.1 GEOLOGIC ENVIRONMENT**

Regionally, the northwesterly trending Santa Clara Valley Basin contains interbedded alluvial, fluvial, and estuarine deposits to a depth of as much as 1,500 feet (Iwamura, 1980). Soils consist of varying combinations of clay, silt, sand, and gravel that represent the interfingering of estuarine and alluvial deposit environments during the late Pleistocene and Holocene epochs. The fluvial soils were derived from the Santa Cruz highlands west of the basin and deposited on an alluvial plain bounded by alluvial fan deposits to the west and baylands to the northeast (Iwamura, 1980). In general, thicker intervals of sand and gravel and discontinuous intervals of clays and silt are found near the upper alluvial fan deposits. The sand and gravel intervals are thin, and clay and silt intervals become thicker and laterally continuous close to the axis of the basin and farther from the fan deposits.

### **5.2 LOCAL GEOLOGY**

A series of geologic cross sections were constructed to better understand the subsurface relationships of the interbedded layers beneath OPHA (Figure 5-1). The cross sections were constructed using subsurface lithologic data from the monitoring well borings and Phase 1, Phase 2, Army, and EPA CPT geologic logs. CPT data were translated to USCS codes using the correlations on Table 5-1, based on professional judgment and site-specific experience on Moffett. The data were input manually into Rockworks<sup>TM</sup> 2004, an integrated geological visualization software package. Once the data were entered into the program, a 3-dimensional lithology solid model was generated. The 3-dimensional lithology model uses a proprietary horizontal lithoblending algorithm that assigns each model node (in this case the X, Y, and Z dimensions were set to 15 feet by 15 feet by 0.25 feet) a lithology value (such as CL, the USCS abbreviation for clay) starting at the nodes closest to the boreholes and expanding in ever-widening circles until a different lithology value is encountered. The resulting lithology model was then viewed in 3-dimensional space to assure applicability of the modeling algorithm with the interpreted fluvial environment of deposition. The cross sections represent slices through the solid model and illustrate the geology and hydrostratigraphy beneath OPHA and the area south of Highway 101. Cross sections A-A', B-B', D-C are included as Plate 5-1. Cross sections C-C', D-D', and E-E' are included as Plate 5-2.

The subsurface beneath OPHA is characterized by interbedded clay, silt, and sand deposits. The following descriptions are based on continuous soil cores collected during groundwater monitoring well installation and from CPT logs.

Clay soils ranged from fines with high plasticity with minor amounts of fine sand, to fines with high plasticity with fine to coarse sand and gravel. Clay thickness ranged from 6 inches (MCH-3UA at depth interval 14 to 14.5 feet bgs) to 9 feet (MCH-4LA and MCH-10LA at depth intervals of 9 to 18 feet bgs and 4 to 13 feet bgs, respectively). Clay color ranged from black, dark gray, and dark bluish-gray, to light olive gray, grayish-brown, and reddish-brown. Clay often included subangular calcareous nodules ranging in size from coarse sand to fine gravel. The calcareous nodules were encountered from near ground surface to total depth. The calcareous nodules were found often in lighter colored clay. Groundwater was not observed in clay samples. Clay was encountered at various depths from near ground surface to approximately 55 feet bgs, the total depth of OPHA investigation. Clay was found most frequently encountered from near ground surface to approximately 10 feet bgs, particularly south of OPHA (see cross section A-A' on Plate 5-1) and on the eastern side of OPHA (see cross sections C-C', D-D', and E-E' on Plate 5-2).

Silt ranged from fines with low to medium plasticity with minor amounts of fine sand, to non-plastic fines with fine to coarse sand and gravel. The low to medium plasticity observed in some silt soils was an indication of clay content. Silt sediment thickness ranged from 6 inches at MCH-5UA at a depth interval of 15 to 15.5 feet bgs, to approximately 38 feet at FW13B at a depth interval of 5 to 43 feet bgs (see cross section B-B' on Plate 5-1). Silt was the most frequently logged soil type, and was encountered at various depths from ground surface to 55 feet bgs. Silt color ranged from variations of dark gray and black usually near ground surface to olive and olive brown. Silt often included subangular calcareous nodules ranging in size from coarse sand to fine gravel. The calcareous nodules were encountered from near ground surface to total depth. Groundwater was occasionally observed in silt with minor amounts of sand. DPT/HydroPunch<sup>®</sup> groundwater samples were occasionally collected from layers logged as silt at CPT and DPT/ HydroPunch<sup>®</sup> locations, such as FW24B at a depth interval of 36 to 37 feet bgs. Not all DPT/HydroPunch<sup>®</sup> sampling attempts from silt zones were successful (CPT and DPT/HydroPunch<sup>®</sup> location FW13B at depth intervals of 10.5 to 12.5 feet bgs and 19.5 to 21.5 feet bgs did not produce groundwater).

Sand soils ranged from fine sand with silt, to medium and coarse, subrounded to subangular sand, with fine subangular gravel. Sand was often olive, dark olive gray, dark grayish-brown and dark bluish-gray in color. Sand sediment thickness ranged from approximately 6 inches (well-graded sand-clayey sand) at MCH-4LA at a depth interval of 38.5 to 39 feet bgs to 14 feet (well-graded sand-silty sand [SM]) at MCH-2LA at a depth interval of 30 to 44 feet bgs). Sand layers were thicker and more prevalent in the upper portion of the A aquifer from about 10 to 25 feet bgs, than in the lower portion of the A aquifer.

The 14-foot-thick sand layer observed at MCH-2LA may be an overestimate of the actual sand thickness at this location (see Section 2.4). “Poor recover” and “potential slough from 39 to 44 feet bgs” are noted on the log. Heaving sands (a sand/groundwater mixture that enters the augers due to reduced pressure within the augers) resulted in poor core recoveries from 39 to 44 feet bgs. On cross sections A-A', B-B', and D-D' (see Plates 5-1 and 5-2), the sand thickness at MCH-2LA was decreased from a depth interval of 30 to 44 feet bgs to 30 to 39 feet bgs to be more consistent with the sand thickness detected at nearby CPT and DPT/HydroPunch<sup>®</sup> location FW41A/FW12B, where sand was detected from 30 to 35 feet bgs. Other locations where sand thickness may have been overestimated due to heaving sands (indicted by “poor recovery” or potential slough” on continuous core logs) were the following:

- MCH-2LA from 14 to 24 feet bgs (reduced to 14 to 22 feet bgs)
- MCH-8LA from 21 to 29 feet bgs (reduced to 21 to 24 feet bgs)
- MCH-10LA from 21.5 to 24 feet bgs (reduced to 21.5 to 22 feet bgs)

The intervals of sand reduction were equal to the interval of “poor recovery” or “potential slough” on the corresponding continuous core log.

### **5.3 REGIONAL HYDROSTRATIGRAPHY**

Groundwater beneath the Moffett, including OPHA, is encountered in the A, B, C, and Deep aquifers (Table 5-2). Only the A aquifer was investigated during this project. The A aquifer consists of multiple interconnected permeable lenses or layers separated by lower permeability layers. The permeable layers consist of sediments ranging from silts and sandy silts to medium to coarse gravelly sands (stream channel deposits). The number, thickness, depths, and interconnection of these permeable layers vary throughout Moffett, including OPHA.

### **5.4 LOCAL HYDROSTRATIGRAPHY**

Low-permeability material, primarily silts and clays, were encountered from ground surface to approximately 10 to 12 feet bgs at most sampling locations. First-observed groundwater was encountered below this relatively impermeable layer. Groundwater was observed under confining conditions at 44 of 46 Phase 1 and Phase 2 DPT/temporary well sample locations. Phase 1 DPT/temporary well sample locations, FW19A and FW20A, were the only locations where the near-surface confining layer was not observed. Near-surface soil at FW19A and FW20A consisted of silty sand and gravel mixtures.

#### **5.4.1 Upper Portion of A Aquifer**

The thickness and horizontal distribution of the upper A aquifer coarse-grained zone is shown on Figure 5-2. The upper A aquifer coarse-grained zone is encountered at elevations from approximately 33 feet to 18 feet above msl (generally the top and bottom of coarse-grained zone, respectively) south of the Highway 101/Moffett Boulevard interchange, and 12 feet to 4 feet

above msl (generally the top and bottom of coarse-grained zone, respectively) along the northeast OPHA boundary. The upper A aquifer coarse-grained zone slopes to the north at a rate of approximately 0.0035 foot per foot (ft/ft). Ground surface at OPHA slopes to the north at a rate of approximately 0.0055 ft/ft. Relatively thick deposits, up to 14 feet, of sand and gravelly sand were encountered from south of the Highway 101/Moffett Boulevard interchange to the southwest corner of OPHA (see Figure 5-2).

Distributions of coarse- and fine-grained soils differ based on location and depth. The coarse-grained soil layers generally trend north-south. Coarse-grained layers are thicker and more laterally extensive in the upper portion of the A aquifer than in the lower portion of the A aquifer. A zone of interconnected coarse-grained soil layers in the upper A aquifer extends from southwest of the Highway 101/Moffett Boulevard interchange to OPHA/NASA property boundary (see cross section A-A' on Plate 5-1). Coarse-grained soil layers were encountered along most of the eastern portion of OPHA (see cross section E-E' on Plate 5-2), but were generally not as thick as those detected through the center of OPHA. Coarse-grained soil layers were not encountered at CPT and DPT/HydroPunch<sup>®</sup> locations FW13B, FW26B, and FW27B in the upper A aquifer along the western portion of OPHA (see Figure 5-2 and cross section B-B' on Plate 5-1). Upper A aquifer coarse-grained soil layers were not detected at the northern portion of OPHA and near the southern OPHA boundary (see Figure 5-2).

#### **5.4.2 Lower Portion of A Aquifer**

The occurrence and thickness of coarse-grained soil layers are less in the lower portion of the A aquifer than in the upper portion of the A aquifer at OPHA. The lower A aquifer coarse-grained soil layers were divided into two zones based on cross section interpretation.

##### **5.4.2.1 Lower A Aquifer Upper Coarse-grained Zone**

The lower A aquifer upper coarse-grained zones (Figure 5-3) includes relatively thin coarse-grained soil layers encountered at elevations between 12 to 2 feet above msl (top and bottom of coarse-grained zone, respectively) at the southern end of cross section A-A', and 6 to 12 feet below msl (top and bottom of coarse-grained zone, respectively) at the north end of cross section A-A'. The lower A aquifer upper coarse-grained zone slopes to the north at a rate of approximately 0.0033 ft/ft. The majority of coarse-grained soil layers in the lower A aquifer upper zone at OPHA are between 1 and 4 feet thick (see Plates 5-1 and 5-2) and were encountered along the southern and southwestern OPHA boundary, extending to the northeast in the north-central portion of OPHA (see Figure 5-3).

##### **5.4.2.2 Lower A Aquifer Lower Coarse-grained Zone**

Two relatively continuous but apparently unconnected sheet-like coarse-grained soil layers characterize the lower A aquifer lower coarse-grained zone, and are observed south of OPHA and in the central OPHA (Figure 5-4). These two coarse-grained soil layers were encountered



between 6 to 14 feet below msl (top and bottom of coarse-grained zone, respectively) at the southern end of cross section A-A', and 14 to 20 feet below msl (top and bottom of coarse-grained zone, respectively) at the northern end of cross section A-A'. The lower A aquifer lower coarse-grained zone slopes to the north at a rate of approximately 0.0017 ft/ft. The majority of coarse-grained soil layers in the lower A aquifer lower coarse-grained zone are between 1 and 4 feet thick.

## **5.5 GROUNDWATER FLOW**

The 11 new OPHA groundwater monitoring wells and 3 existing wells located east of OPHA (87B1, W89-6, and W89-7) were gauged on August 8, 2005, November 17, 2005, December 7, 2005, March 21, 2006, and June 12, 2006. The depth to groundwater level measurements were converted to msl and contoured with Surfer<sup>®</sup> using the “nearest neighbor” method. The contours were then reviewed by a California professional geologist and adjusted as required using best professional judgment, along with an understanding of the hydrogeology of Moffett.

Potentiometric surface maps for the upper and lower portions of the A aquifer, for the August 2005 gauging event are included as Figures 5-5 and 5-6. Groundwater monitoring wells on the west side of Moffett, including the 13 wells gauged as part of OPHA investigation, were gauged as part of the November 2005 regional “Black Thursday” gauging event. Potentiometric surface maps for the upper and lower portions of the A aquifer, for the west side of Moffett are included as Figures 5-7 and 5-8. Groundwater flow due west of the Moffett runway, in the upper and lower portion of the A aquifer is generally to the north-northwest. Groundwater flow is generally to the north-northeast throughout central Moffett, and generally to the north-northwest along the western portion of Moffett, including OPHA. Water level trends for the five water level measurements for OPHA wells are included as Figures 5-9 and 5-10.

### **5.5.1 OPHA Water Level Trends**

Figures 5-9 and 5-10 show water levels vs. time hydrographs for the upper and lower portion of the A aquifer, respectfully. The trends show that during the 2005/2006 wet season (see Figure 5-13 showing daily precipitation for Moffett) water levels in both the upper and lower portion of the A aquifer rose at about the same rate. In addition, the water level trends for monitoring wells in both the upper and lower A aquifer are nearly parallel (water levels rise and fall at about the same rate in all OPHA monitoring wells). The latter implies that the groundwater flow direction(s), and horizontal and vertical gradient(s) do not change throughout the year from the wet to the dry season. Therefore, a contour plot of any quarter of data generally represents the groundwater flow direction(s) and gradient(s) for the entire year.

### **5.5.2 Moffett Area Groundwater Flow**

The November 2005 Black Thursday water level measurement event included OPHA monitoring wells. The depth to groundwater level measurements were converted to msl and contoured with

Surfer<sup>®</sup> using the nearest neighbor method. The contours were then reviewed by a California professional geologist and adjusted as required using best professional judgment, along with an understanding of the hydrogeology of Moffett.

The groundwater contours for both the upper and lower portions of the A aquifer in OPHA (Figures 5-7 and 5-8, respectively) are consistent with the remainder of Moffett. There appears to be some influence of water levels in the western portion of OPHA by Stevens Creek.

### **5.5.3 OPHA Groundwater Flow**

Flow direction and potentiometric surface gradient in the upper portions of the A aquifer were nearly identical for all five water level gauging events (see Section 5.5.1). Flow direction for the upper portion of the A aquifer was to the north-northwest at a gradient of approximately 0.007 ft/ft throughout most of OPHA (see Figure 5-5). The relatively consistent gradient in the upper portion of the A aquifer across OPHA is most likely due the extensive coarse-grained soil layers encountered throughout most of the upper A aquifer. An exception may be along the southern boundary where fine-grained material encountered near the southeastern and southwestern OPHA boundary most likely directs groundwater flowing onto OPHA to the coarse-grained soil channels located near the center of the southern OPHA boundary (see Figure 5-2). Wells W89-6 and W89-7, measured for this investigation, but located to the east of OPHA, are cross-gradient from OPHA (see Figures 5-5 and 5-7).

Flow direction and potentiometric surface gradient in the lower portions of the A aquifer were also similar for all five water level gauging events (see Section 5.5.1). Flow direction for the lower portion of the A aquifer is generally to the north-northwest at a gradient of approximately 0.008 ft/ft throughout the southern third of OPHA and increases to approximately 0.01 ft/ft in the central third of OPHA (see Figure 5-6). The flow direction and potentiometric surface gradient are a function of the lower A aquifer geology. Groundwater flowing onto the site from the south is most likely restricted by the lower permeability of the large silt layer encountered in all but the westernmost portion of OPHA (see Figure 5-3). The restricted flow through the silt results in steeper gradients. Groundwater would flow preferentially through the coarse-grained soil layers encountered along the western OPHA boundary. Potentiometric surface gradient through the silt is approximately 0.01 ft/ft. Potentiometric surface gradient through the coarse-grained soil layers encountered along the western OPHA boundary is approximately 0.0065 ft/ft. Well 87-B1, measured for this investigation, but located to the east of OPHA, is cross-gradient from OPHA (see Figures 5-6 and 5-8).

The flow in Stevens Creek, which may have an influence on the groundwater flow direction in the upper and lower portions of the A aquifer during both events, was relatively low throughout the year. Stevens Creek is located along the western boundary of OPHA.

#### 5.5.4 OPHA Vertical Groundwater Flow

Two well pairs were installed on OPHA. Well pair MCH-1UA/2LA is located near the southwest boundary. MCH-1UA is screened from 14 to 24 feet bgs. MCH-2LA is screened from 32 to 40 feet bgs. The water elevation was 0.03 feet, 0.01 feet, 0.01 feet, and 0.05 feet higher in the MCH-2LA than in MCH-1UA in August, November, and December 2005, and June 2006, respectively (see Figure 5-11). The water elevation was 0.23 feet higher in MCH-1UA than in MCH-2LA in March 2006. The difference in water levels indicates minimal potential for upward groundwater movement from the lower A aquifer to the upper A aquifer at MCH-1UA/2LA during the dry season. During the dry season the vertical gradients range from 0.001 ft/ft to 0.006 ft/ft (assuming a distance from the bottom of the screen at MCH-1UA to the top of the screen at MCH-2LA). During the wet season there is a downward potential (vertical gradient of 0.03 ft/ft).

Well pair MCH-7UA/8LA is located near the west-central portion of OPHA. MCH-7UA is screened from 10 to 20 feet bgs. MCH-8LA is screened from 35 to 45 feet bgs. The water level was 0.64 feet, 0.60 feet, 0.72 feet, 1.39 feet, and 0.63 feet higher in MCH-7UA than in MCH-8LA in August, November, and December 2005, and March and June 2006, respectively (see figure 5-12). The difference in water levels indicates the potential for groundwater movement from the upper portion of the A aquifer to the lower portion of the A aquifer in this area throughout the year. The vertical gradients range from 0.04 ft/ft to 0.09 ft/ft (assuming a distance from the bottom of the screen at MCH-7UA to the top of the screen at MCH-8LA).

Superimposing the August 2005 potentiometric surface map from the upper portion of the A aquifer (Figure 5-5) onto the August 2005 potentiometric surface map of the lower portion of the A aquifer (Figure 5-6) shows a only a minor water level difference throughout most of the southern third of OPHA. The water level difference in the southwest corner of OPHA was 0.03 feet upward (at well pair MCH-1UA/MCH-2LA [vertical gradient of 0.004 ft/ft]). For most of the central portion of OPHA there is a downward water level potential. The water level difference at well pair MCH-7UA/MCH-8LA was 0.64 feet downward (vertical gradient of 0.04 ft/ft). There are insufficient data to determine the water level potential in the northern portion of OPHA.

#### 5.6 GROUNDWATER GEOCHEMISTRY

Data for major cations (calcium, sodium, magnesium, and potassium) and anions (bicarbonate, carbonate, chloride, nitrate/nitrite-N, and sulfate) were collected from the first two sampling events (August and December 2005) in order to determine the geochemistry of groundwater in the upper and lower portions of the A aquifer, and to determine whether there is any geochemical difference between the upper and lower portion of the A aquifer.

Major cation and anion data were evaluated using Aquachem<sup>®</sup> software. Piper plots for the August and December 2005 sampling events are presented in Figure 5-14. Piper plots provide a

snapshot of the geochemistry relative to the percent abundance of each ionic species. The Piper plots for each sampling event show that all wells cluster within a single area, thus indicating that wells screened within the upper and lower portions of the A aquifer exhibit similar geochemistry. In addition, groundwater geochemistry shows no spatial variability.

Groundwater within the A aquifer is characterized as a calcium-bicarbonate water with secondary components of magnesium and sulfate. Based on stabilized field parameter measurements taken in August 2005, specific conductivity for the 14 wells sampled ranged from 976 micromhos per centimeter ( $\mu\text{mhos/cm}$ ) in MCH-6LA to 1,679  $\mu\text{mhos/cm}$  in W89-7. Corresponding calculated total dissolved solids for MCH-6LA and W89-7 are 677 and 1,240 mg/L, respectively, thus classifying the groundwater at Moffett Community Housing as non-saline to slightly saline (Hem, 1989).

The accuracy of the analyses of major constituents in groundwater can be evaluated by calculating the cation-anion balance, which compares the sum of the cations in milliequivalents per liter (meq/L) to the sum of anions in meq/L. Since major constituents in groundwater have an analytical accuracy of 2 to 10 percent (Hem, 1989), cation-anion balances less than 10 percent indicate that the accuracy of analytical results are acceptable for use in data evaluation. Results for the August 2005, sampling event indicate cation-anion balances ranging from 10.6 to 12.7 percent. During the December 2005 sampling event, the cation-anion balances decreased for all wells, ranging from 5.5 to 9.2 percent, which is within the acceptable range for accuracy. The decrease in cation-anion balance in December 2005 can be attributable to the stabilization of the wells subsequent to their installation, development, and initial sampling event earlier in the year.

## **6.0 CONTAMINATION DISTRIBUTION AND MIGRATION**

Understanding the fate of groundwater contamination within OPHA is dependent on interpreting the relationship between contaminant distribution, source identification, and site hydrostratigraphy. The primary VOCs in groundwater at OPHA are the chlorinated solvent TCE, and its breakdown product cis-1,2-DCE. The compounds 1,1-DCE and trans-1,2-DCE are found at low to trace levels (generally less than 1 µg/L) in samples collected from most OPHA wells. In addition, there are low to trace levels of VC in a few select wells and PCE in one well at OPHA. Trans-1,2-DCE and 1,1-DCE are not discussed further since they are generally at trace levels and do not provide additional information about site conditions at OPHA.

A conceptual site model (CSM) of OPHA has been developed by combining the analytical information collected to date, including the stable isotope study result, and a comprehensive interpretation of the site hydrostratigraphy. The CSM presented in this section provides an explanation of contaminant source, migration, and fate.

### **6.1 CONCENTRATION TRENDS OF VOCS IN GROUNDWATER**

This section presents information on the concentration trends of TCE and cis-1,2-DCE within the upper and lower portions of the A aquifer. Trends for PCE, VC, trans-1,2-DCE, and 1,1-DCE are not discussed since they are generally at trace levels and/or are only found in one or a few select groundwater wells.

#### **6.1.1 TCE CONCENTRATION TRENDS**

The 4 quarters of groundwater samples appear to show a seasonal effect on TCE concentrations in both the upper and lower A aquifer wells. There are decreases in TCE concentrations during the March 2006 wet season sampling event (see Figures 5-9, 5-10, and 5-13 showing water level trends and precipitation), most likely due to recharge/dilution (see Section 5.5.4). TCE concentrations in samples collected in the subsequent June 2006 sampling event (during a dry period) increase to near pre-wet season concentrations. There appears to be a slight overall decline in TCE concentration during the four quarters of sample collection. The March 2006 TCE concentration in the sample collected from well MCH-6LA is considered anomalous.

The majority of TCE concentration trends for the samples from upper and lower A groundwater wells parallel each other (see Figures 6-1 and 6-2). Although TCE concentrations appear to be impacted seasonally, the parallel trends imply that the TCE concentration distribution does not change throughout the year from the wet to the dry season. Therefore, the distribution of TCE throughout the year is relatively constant and a contour plot of any quarter of data is representative of the entire year.

### **6.1.2 CIS-1,2-DCE CONCENTRATION TRENDS**

The four quarters of groundwater samples appear to show a minor seasonal effect on cis-1,2-DCE concentrations in the upper A aquifer wells, except for samples from well W89-6. The cis-1,2-DCE concentrations/trend from well W89-6 is not impacted by or does not impact OPHA, since this well is cross-gradient from OPHA. The cis-1,2-DCE trends for the upper portion of the A aquifer appear to be similar to the TCE trends for the upper portion of the A aquifer (see Section 6.1.1). The cis-1,2-DCE concentrations in the upper portion of the A aquifer do not appear to be inversely related to TCE concentrations; if reductive dechlorination of TCE was occurring, one would anticipate seeing an increase in cis-1,2-DCE concentration with a decrease in TCE concentration [see Figures 6-1 and 6-3].

There is no apparent trend in cis-1,2-DCE concentration in samples collected from all but one of the groundwater wells from the lower portion of the A aquifer (see Figure 6-4). The cis-1,2-DCE concentration trend in samples from upgradient well MCH-2LA is similar in shape to the cis-1,2-DCE concentrations in samples collected from the upper A aquifer wells, except there does not appear to be an increase in cis-1,2-DCE concentration during the June 2006 sampling event. The significantly higher cis-1,2-DCE concentrations in samples from upgradient well MCH-2LA could be caused by a different source of groundwater flowing onto OPHA and/or localized enhanced reductive dechlorination; this correlates with the lower concentrations of TCE in samples collected from MCH-2LA (lower than all other OPHA wells - see Figure 6-2).

The majority of cis-1,2-DCE concentration trends for the samples from the upper A groundwater wells parallel each other (see Figure 6-3). Although cis-1,2-DCE concentrations appear to have a minor seasonality, the parallel trends imply that the cis-1,2-DCE concentration distribution does not change throughout the year from the wet to the dry season. Therefore, the distribution of cis-1,2-DCE throughout the year is relatively constant and a contour plot of any quarter of data is representative of the entire year.

## **6.2 DISTRIBUTION OF VOCs IN GROUNDWATER**

TCE and its breakdown product cis-1,2-DCE are the primary contaminants in groundwater underlying OPHA. TCE occurs at the highest concentrations. Additionally, TCE and cis-1,2-DCE are more widespread than any other VOC. Evaluation of the distribution of TCE and cis-1,2-DCE in groundwater provides the most complete picture of groundwater contamination underlying OPHA. VC contamination in groundwater is found in samples from select wells at greater than trace concentrations. The contamination appears to identify upgradient sources of groundwater contributing to contamination found underlying OPHA and/or local areas of enhanced reductive dechlorination (see Section 6.2.4.1). PCE contamination in groundwater is found in samples from only one well. The PCE contamination also appears to identify upgradient sources of groundwater contributing to contamination found underlying OPHA (see Section 6.2.4.2).

## 6.2.1 TCE and Cis-1,2-DCE Groundwater Data Comparability

There have been multiple investigations by multiple parties (Army, EPA, and Navy) over the last 5 years to evaluate the contamination at OPHA and the surrounding areas. A comparison of the sampling results was made to evaluate the suitability of combining all available data (monitoring well data, DPT/temporary well data, and DPT/HydroPunch® data) as a single data set. The comparison focused on TCE and cis-1,2-DCE data results. TCE and cis-1,2-DCE concentrations from groundwater samples collected at various times and by various methods over differing sampling intervals were compared. The 11 new monitoring wells installed at OPHA have well screen lengths of 10 feet. The Phase 1 DPT/temporary wells had screen lengths of 5 feet. Phase 1 and Phase 2 DPT/HydroPunch® groundwater samples were collected using 1- to 2-foot screened intervals.

Groundwater monitoring wells were sampled in August and December 2005, and March and June 2006. Monitoring well groundwater sample TCE concentrations showed a seasonal effect (see Section 6.1.1). Therefore, the TCE concentrations for monitoring well samples from the August 2005, sampling event (dry season) were primarily used in the comparisons with the August/September 2002, DPT/temporary well and DPT/HydroPunch® samples (dry season). Likewise, the TCE concentrations for monitoring well samples from the March 2006 sampling event (wet season) were primarily used in the comparisons with the February 2002 DPT/temporary well and DPT/HydroPunch® samples (wet season). However, the other 3 quarters of monitoring well TCE data were also used in the comparison, but with a lesser emphasis. TCE concentrations from upper A aquifer groundwater monitoring well samples were compared to TCE concentrations from upper A aquifer DPT/temporary wells and/or DPT/HydroPunch® groundwater samples as shown in Table 6-1. A similar comparison was made for cis-1,2-DCE concentrations.

In general, TCE and cis-1,2-DCE concentrations in groundwater samples collected from the upper A aquifer monitoring wells and in groundwater samples collected from upper A aquifer DPT/HydroPunch® locations and DPT/temporary well locations in 2002 were similar (see Table-6-1). The similarities are reasonable, considering most of the upper A aquifer wells were installed within interconnected north-south-trending coarse-grained soil layers (see Section 5.4). An exception in the comparison was monitoring well MCH-5UA, with a TCE sample concentrations ranging from 36 µg/L to 50 µg/L and nearby DPT/temporary well location FW15B with a TCE sample concentration of 210 µg/L. All other groundwater sample TCE and cis-1,2-DCE concentrations (monitoring well, DPT/temporary wells, and DPT/HydroPunch®) from the upper portion of the A aquifer are comparable. Therefore, TCE and cis-1,2-DCE concentrations from upper A aquifer groundwater monitoring well, shallow DPT/temporary well, and shallow DPT/HydroPunch® samples have been combined as single data sets and contoured to describe the distribution in OPHA (see Sections 6.2.2.1 and 6.2.3).

TCE and cis-1,2-DCE concentrations from lower A aquifer groundwater monitoring well samples were compared to TCE and cis-1,2-DCE concentrations, respectively from lower A aquifer DPT/HydroPunch<sup>®</sup> groundwater samples collected in 2002 as shown in Table 6-2. TCE concentrations in groundwater samples collected from lower A aquifer monitoring wells and groundwater samples collected from lower A aquifer DPT/HydroPunch<sup>®</sup> locations are similar in some locations and differ in other locations. The absence of laterally extensive interconnected coarse-grained soil layers in the lower A aquifer (see Section 5.4) is believed to explain the lesser comparability between the groundwater monitoring well and 2002, DPT/HydroPunch<sup>®</sup> sample results observed in the lower A aquifer. Site geology in the lower portion of the A aquifer varies greatly over relatively short distances, as does TCE concentrations. For example, MCH-8LA located 200 feet north of CPT and DPT/HydroPunch<sup>®</sup> boring FW17B, had an estimated TCE concentration of 3 µg/L, while the sample collected from FW17B had a TCE concentration of 1,100 µg/L. Assuming that the lack of similarity between TCE concentrations of samples collected from groundwater monitoring wells and DPT/HydroPunch<sup>®</sup> samples is a result of the hydrostratigraphy and not the sampling methodology or when the sample was collected, the data sets have been combined and contoured as a single data set. However, there is a lower degree of confidence in the lower A aquifer TCE contours compared to the upper A aquifer TCE contours.

Cis-1,2-DCE concentrations in groundwater samples collected from lower A aquifer monitoring wells and groundwater samples collected from lower A aquifer DPT/HydroPunch<sup>®</sup> locations are generally similar. Therefore, cis-1,2-DCE concentrations from lower A aquifer groundwater monitoring well and DPT/HydroPunch<sup>®</sup> samples have been combined as a single data set and contoured to describe the distribution in OPHA.

### **6.2.2 TCE Distribution in the A Aquifer**

Groundwater TCE concentration trends for OPHA wells generally parallel each other (see Section 6.1.1). Although TCE concentrations appear to be impacted seasonally, the parallel trends imply that the TCE concentration distribution does not change throughout the year from the wet to the dry season. Therefore, the distribution of TCE throughout the year is relatively constant and a contour plot of any quarter of data is representative of the entire year. Therefore, the TCE concentrations for monitoring well samples from the December 2005, sampling event were used in the following comparisons.

TCE isoconcentration contours for the upper and lower portions of the A aquifer are shown on Figure 6-5 and Figure 6-6, respectively. The figures were developed using the August 2005, TCE concentrations at the monitoring wells and the one-time DPT/temporary well and DPT/HydroPunch<sup>®</sup> samples. VOC analytical results from the following investigations have been included in the contamination distribution evaluation (see Sections 1.2 and 3.1.1):

- OPHA well sampling in August and December 2005



- The Navy's Phase 1 and Phase 2 investigations in 2003
- The Army and EPA's upgradient off-site investigations in 2003, and 2005, respectively
- The Navy's groundwater sampling in 1999
- NASA's HydroPunch<sup>®</sup> and well sampling in 1999

#### **6.2.2.1 TCE in the Upper Portion of the A Aquifer**

TCE was detected upgradient of OPHA in the upper A aquifer at a maximum concentration of 440 µg/L at a depth of 21.5 feet in a sample collected from EPA CPT and DPT/HydroPunch<sup>®</sup> location HP03 (see Figure 6-5). However, unlike all other groundwater samples collected on- and off-site that were analyzed using EPA Method 8260B, a hazardous waste method, EPA groundwater samples were analyzed for VOCs using EPA Method 524.2, a drinking water method. EPA Method 524.2 is typically used to detect low levels of contamination in drinking water. EPA Method 524.2 is designed for samples with low matrix interference, is not typically used to evaluate contaminated groundwater, and is not appropriate for samples with high sediment content (such as samples collected using HydroPunch<sup>®</sup> equipment) and high VOC concentrations (EPA, 2004a; 1995). The 440-µg/L TCE sample concentration at HP03 may not be representative of site-specific conditions. HP03 is located in the Santa Clara County vector control yard, southwest of the Highway 101/Moffett Boulevard interchange. Because a different analytical method (EPA Method 524.2) and different laboratory were used to analyze EPA samples, results from the EPA investigation, although combined with the Army and Navy investigation results, are considered less comparable. Isoconcentration contours near EPA data points are presented as inferred on Figures 6-5 through 6-11.

The extent of TCE in the Upper A aquifer south and east of the Santa Clara County vector control yard appears to be well-characterized by HP18, HP11, HP04, HP05, HP09 HP06, HP10, HP08, and HP14. The distribution of TCE in groundwater west of the vector control yard is not defined.

TCE is migrating onto OPHA, in the upper A aquifer, across the southern border. Relatively consistent TCE concentrations (approximately 200 to 350 µg/L) were detected at the southern OPHA border, throughout the length of OPHA, and onto NASA property, along a band trending south to north (see Figure 6-5). The TCE migration pathway appears to follow the contiguous zone of coarse-grained soil layers in the upper A aquifer (see Section 5.4.1) and, generally, the groundwater flow direction (see Section 5.5.2). An exception to the flow-through TCE distribution pattern in the upper A aquifer is observed in a sample collected from MCH-9UA, where the maximum upper A aquifer TCE concentration (610 µg/L) was detected. A CSM explaining the observed concentration at MCH-9UA is developed in Section 6.5.

### **6.2.2.2 TCE in the Lower Portion of the A Aquifer**

Similar to groundwater in the upper A aquifer, TCE was detected south and upgradient of OPHA in the lower A aquifer at a maximum concentration of 875 µg/L in a sample collected from SIG5 (see Figure 6-6). TCE is migrating onto OPHA, in the lower A aquifer, across the southern border. TCE concentrations on OPHA, along the southern (upgradient) border, ranged from 160 µg/L in a sample collected from FW07A to 520 µg/L in a sample collected from MCH-4LA.

The lower A aquifer TCE distribution pattern suggests that migration of TCE is influenced by local groundwater flow direction and hydrostratigraphy. The preferential contaminant migration pathway flows northward onto OPHA across the southern boundary, moves northward across the western OPHA boundary, then to the northeast, following the groundwater flow direction and the coarse-grained soil layers, to the west-central portion of the site (see Sections 5.4.2 and 5.5.2). Elevated TCE concentrations (from 120 to 1,200 µg/L) were detected in a thin coarse-grained deposit encountered in the central OPHA at approximately 40 feet bgs in samples collected from MCH-6LA, FW17B, FW16B, FW18B, and MCH-10LA. The highest concentrations of TCE in the A aquifer at OPHA were detected in the lower portion of the A aquifer. Higher TCE concentrations in the lower A aquifer may be related to the hydrostratigraphy of the lower A aquifer, which contains finer-grained materials that absorb TCE, thereby slowing the rate of migration. A CSM explaining the observed concentrations is developed in Section 6.5.

### **6.2.3 CIS-1,2-DCE Distribution in the A Aquifer**

Groundwater sample cis-1,2-DCE concentration trends for OPHA wells generally parallel each other (see Section 6.1.2). Although cis-1,2-DCE concentrations appear to have a minor seasonality, the parallel trends imply that the cis-1,2-DCE concentration distribution does not change throughout the year from the wet to the dry season. Therefore, the distribution of cis-1,2-DCE throughout the year is relatively constant and a contour plot of any quarter of data is representative of the entire year. Therefore, the cis-1,2-DCE concentrations for monitoring well samples from the December 2005 sampling event were used in the following comparisons.

Cis-1,2-DCE isoconcentration contours for the upper and lower portions of the A aquifer are shown on Figure 6-7 and Figure 6-8, respectively. The figures were developed using the August 2005 cis-1,2-DCE concentrations at the monitoring wells and the one-time DPT/temporary well and DPT/HydroPunch<sup>®</sup> samples. VOC analytical results from the following investigations have been included in the contamination distribution evaluation (see Sections 1.2 and 3.1.1):

- OPHA well sampling in August and December 2005, and March and June 2006
- The Navy's Phase 1 and Phase 2 investigations in 2003
- The Army and EPA's upgradient off-site investigations in 2003 and 2005, respectively

- The Navy's groundwater sampling in 1999
- NASA's HydroPunch<sup>®</sup> and well sampling in 1999

The cis-1,2-DCE plume is similar in nature and extent to the TCE plume in the upper portion of the A aquifer (see Figure 6-5), although concentrations of cis-1,2-DCE are generally lower than TCE concentrations. Similar to the distribution noted in the upper portion of the A aquifer, the nature and extent of the cis-1,2-DCE plume in the lower portion of the A aquifer (see Figure 6-6) is generally similar to the TCE plume in the lower portion of the A aquifer. Cis-1,2-DCE is migrating onto OPHA in the upper and lower A aquifer across the upgradient (southern) border.

The maximum upper A aquifer cis-1,2-DCE concentration (740 µg/L) was detected upgradient of OPHA at the Santa Clara County vector control yard in a sample collected by the EPA at location HP03 (however, there is uncertainty in the comparability between the EPA results with the Navy and Army results due to the different analysis method (see Section 6.2.2.1). The maximum lower A aquifer cis-1,2-DCE concentration (980 µg/L) was detected upgradient of OPHA in the southwest portion of the Highway 101/Moffett Boulevard interchange in a sample collected by the Army at location SIG19. Army sample location SIG19 is located downgradient from the Santa Clara County vector control yard.

## **6.2.4 Distribution of Other VOCs in Groundwater**

The distributions of VC and PCE chemicals are discussed below in order to provide a comprehensive evaluation of chlorinated solvents in groundwater at OPHA.

### **6.2.4.1 Distribution of VC**

Figures 6-9 through 6-10 present groundwater contaminant distribution maps for VC for the upper and lower portions of the A aquifer. VC in the upper portion of the A aquifer with concentrations greater than 2 µg/L is limited to three localized areas (see Figure 6-9). The maximum upper A aquifer VC concentration (330 µg/L) was detected cross-gradient of OPHA in a sample collected from monitoring well W89-6. VC was detected at concentrations greater than 2 µg/L in samples collected from locations east of OPHA, near the southwest portion of OPHA, and at one location near the northeast OPHA boundary. The significantly higher VC concentrations in samples from cross-gradient well W89-6 (Figures 6-9 and 6-11) may be due to upward migration and reductive dechlorination of TCE to VC from the lower portion of the A aquifer, which is part of the Middlefield-Ellis-Whisman (MEW) regional VOC plume (TtEC, 2006). Since well W89-6 is cross-gradient from OPHA, the concentrations are not related to OPHA.

The low concentrations of VC reported in the area of DPT/HydroPunch<sup>®</sup> samples FW03B and FW12B (see Figure 6-9) could be caused by a different source of groundwater flowing onto OPHA, localized enhanced reductive dechlorination, and/or upward migration from the lower

portion of the A aquifer (there is some upward potential in this area – see Section 5.5.3). It is likely that the low concentration of VC reported in the sample FW24B/FW18A is due to reductive dechlorination of the OPHA TCE plume.

VC in the lower portion of the A aquifer with concentrations greater than 2 µg/L is limited to the southwest corner and to the south of OPHA (see Figures 6-10 and 6-12). The maximum lower A aquifer VC concentration (30 µg/L) was detected upgradient of OPHA in a sample collected by the Army at location SIG19. Sample location SIG19 is also the location of the maximum lower A aquifer cis-1,2-DCE concentration. The significantly higher VC concentrations in samples from upgradient well MCH-2LA (Figure 6-12) and DPT/HydroPunch® samples FW41A, FW12B, SIG8, and SIG19 suggest a different source of groundwater flowing onto OPHA from the other onsite monitoring wells and localized enhanced reductive dechlorination. VC in the lower portion of the A aquifer is migrating onto OPHA across the upgradient boundary (see Figure 6-10).

#### **6.2.4.2 Distribution of PCE**

PCE was only detected in samples from groundwater in the upper portion of the A aquifer south of OPHA. PCE in the upper portion of the A aquifer at concentrations greater than 5 µg/L is limited to a localized area upgradient (south-southeast) of OPHA (see Figure 6-13), and appears to be associated with the current or historic dry cleaning facilities located south southeast of OPHA. PCE was only detected in samples collected from upper A aquifer well MCH-3UA within OPHA at estimated concentrations below laboratory reporting limits. PCE was detected at locations upgradient of OPHA, and is migrating onto OPHA. PCE was not detected above laboratory reporting limits in samples collected from any lower A aquifer monitoring well, temporary DPT/temporary well, or DPT/HydroPunch® sample.

### **6.3 COMPARISON OF TCE AND CIS-1,2-DCE**

The relative concentrations of TCE and cis-1,2-DCE in groundwater samples collected from monitoring wells were evaluated to determine whether there is a relationship between these two chemicals to support 1) the evaluation of potential sources; and 2) the CSM. Table 6-3 presents the analytical results and ratios calculated for the August and December 2005, and March and June 2006 sampling events. A ratio analysis assumes relatively constant subsurface conditions (e.g., that the effects of transport heterogeneity are minimal, there is relatively constant oxygen content, and that there are not multiple releases) (Morrison, 2000). This interpretative methodology is typically applied to chlorinated solvent sites, even though constant subsurface conditions are rare. Since there is transport heterogeneity at OPHA, interpretations of the ratio method are thus used with a lower degree of certainty for OPHA.

The only cis-1,2-DCE/TCE ratio that looks anomalous is the upper A aquifer well W89-6, located to the southeast of OPHA. TCE concentrations in samples collected from the general

location of well W89-6 have been low (see Figure 6-5). However, the cis-1,2-DCE and VC concentrations in samples collected from this well in August and December 2005, and March and June 2006 had relatively high concentrations (see Figures 6-3 and 6-11). Well W89-6 is cross-gradient from OPHA (see Section 5.5.2). Although it is possible that same upgradient sources impact the groundwater in Well W89-6 and OPHA wells, water from Well W89-6 is not affected by nor affects OPHA wells. The source of TCE and/or cis-1,2-DCE in samples collected from well W89-6 is unknown, but could originate from upgradient sources and/or upwelling from the lower portion of the A aquifer (which is related to the regional plume [TtEC, 2006]).

Generally, ratios were about the same in samples collected from the upper and lower portion of the A aquifer from OPHA wells during all four sampling events. The uniformity in ratios is likely due to uniform biodegradation rates across OPHA and does not suggest any on site sources. The highest ratios for OPHA wells were consistently calculated for wells MCH-2LA, MCH-1UA, and MCH-3UA. All three of these wells are upgradient monitoring wells for OPHA, and are screened across coarse-grained soil layers. Well MCH-4LA, also an upgradient well, has a lower cis-1,2-DCE/TCE ratio, but is screened across somewhat finer-grained soil layers. Wells screened across high permeable material having higher cis-1,2-DCE/TCE ratios and upgradient wells having the highest cis-1,2-DCE/TCE ratios are consistent with the CSM described in Section 6.5. Monitoring wells MCH-7UA and MCH-11UA also had somewhat elevated cis-1,2-DCE/TCE ratios. These two monitoring wells are screened across the continuous coarse-grained soil layers of the upper A aquifer.

In general, it appears that there are three conclusions that can be drawn from the cis-1,2-DCE/TCE ratios at OPHA, as described below:

- The upgradient wells have the highest cis-1,2-DCE/TCE ratios
- There are relatively consistent ratios across most of the upper A aquifer wells. There is less consistency of ratios in the lower A aquifer wells.
- Wells screened across higher permeable materials have higher cis-1,2-DCE/TCE ratios

These interpretations add to information (another line of evidence) used to develop the CSM.

## **6.4 STABLE ISOTOPE STUDY RESULTS**

A stable isotope study was conducted at the request of the Water Board. The primary objective of the stable isotope study was to evaluate whether the TCE beneath OPHA originated from off-site and/or on-site sources. This section provides a summary of the stable isotope study and its application as a line of evidence for the CSM. Isotope study methodology and an analysis of the study are included in Appendix F.

TCE, with a chemical formula of  $C_2HCl_3$ , is composed of three elements: chlorine (Cl), carbon (C), and hydrogen (H). Each element has several isotopes, with two stable isotopes occurring for each element. Only the Cl and C isotopes were analyzed and evaluated for OPHA stable isotope study.

- Chlorine – Two stable isotopes,  $^{35}Cl$  and  $^{37}Cl$  that occur naturally in a ratio of approximately 3:1.  $^{37}Cl/^{35}Cl$  ratios are reported in terms of permil (‰) deviation relative to Standard Mean Ocean Chloride ( $\delta^{37}Cl_{SMOC}$ ) using the conventional  $\delta$  notation.
- Carbon – Two stable isotopes,  $^{12}C$  and  $^{13}C$ , that occur naturally in a ratio of approximately 89:1.  $^{13}C/^{12}C$  ratios are reported in terms of ‰ deviation relative to Pee Dee Belemnite ( $\delta^{13}C_{PDB}$ ) using the conventional  $\delta$  notation.

Notations of the stable isotope ratios for Cl and C are presented as  $\delta^{37}Cl$  and  $\delta^{13}C$ , respectively.

The  $\delta^{37}Cl$  and  $\delta^{13}C$  values for TCE from different sources vary and can be used to differentiate and identify via “isotopic ratio signatures” specific sources of TCE. Recent studies have used stable isotopes to differentiate between different zones in chlorinated ethane plumes and to link plume sources (Hunkeler et al., 2004). Additionally, the  $\delta^{37}Cl$  and  $\delta^{13}C$  values from a specific TCE source are unaffected by dilution mechanisms and will remain constant (see Appendix F) unless natural attenuation of TCE by microbial biodegradation results in a shift of the  $\delta^{37}Cl$  and  $\delta^{13}C$  values (enrichment of the heavier  $^{37}Cl$  and  $^{13}C$  isotopes called the kinetic isotope effect). TCE undergoing microbial biodegradation at a site-wide uniform rate exhibits isotope enrichment that follows a predictable kinetic isotope effect trendline (see Appendix F).

To see whether distinct isotopic ratio signatures were present,  $\delta^{37}Cl$  vs.  $\delta^{13}C$  were plotted (Figures F-3 and F-4 in Appendix F). Plots with a single TCE source and no biodegradation occurring should show a “cluster” as a single group. TCE originating from different sources without biodegradation should appear as “multiple clusters”, the number of which would correspond to the number of different sources of TCE. Several distinct isotopic ratio signatures exist on the  $\delta^{37}Cl$  vs.  $\delta^{13}C$  plots (see Figures F-3 and F-4 in Appendix F), suggesting multiple sources. Cluster analysis (an exploratory data analysis tool that uses algorithms for grouping different observations in a way that the degree of association between observations is maximal if they belong to the same group and minimal otherwise [Statsoft, 2006]) suggests multiple clusters, which concurs with the  $\delta^{37}Cl$  vs.  $\delta^{13}C$  plots suggesting more than one source for the TCE underlying OPHA. A detailed description of the clustering process and results are included in Appendix F.

If the TCE has undergone biodegradation (as is apparent at OPHA by the presence of cis-1,2-DCE, a degradation product of TCE), there will be an isotopic enrichment of the  $\delta^{37}Cl$  and  $\delta^{13}C$  values (kinetic isotope effect) from the original TCE source material that follows a predictable kinetic isotope effect trendline equation if biodegradation is uniform across the site. To

demonstrate the kinetic isotope effect graphically, the  $\delta^{37}\text{Cl}$  and  $\delta^{13}\text{C}$  values were plotted on arithmetic axes against the logarithm of the TCE concentration for August and December 2005 (Figures 6-14 and 6-15, respectively). Compounds that exhibit a kinetic isotope effect representative of a uniform biodegradation rate will be linear on the semi-log plot and show the isotopic enrichment along the progression that biodegradation is proceeding from a common source material. However, if the  $\delta^{37}\text{Cl}$  and  $\delta^{13}\text{C}$  values were plotted using arithmetic scales, compounds that exhibit a kinetic isotope effect representative of a uniform biodegradation rate will plot as a curve (Rayleigh distillation curve) (Chu et al., 2004). The regression lines on Figures 6-14 and 6-15 show the exponential isotopic enrichment occurring from the uniform biodegradation process at the site, and that the majority of the wells fall along this line is evidence that the biodegradation rate is uniform and is occurring from the same original source material. The wells do not plot in the order of distance from the source due to slug flow and various hydrogeologic factors described in Section 6.5. An upper and lower confidence interval for the regression line was then calculated using the coefficient of variation to normalize the data and test if there were well isotopic signatures that lie outside the confidence interval boundaries and thus, indicate different TCE sources, or if multiple linear kinetic isotope effects are present on the plots, different biodegradation mechanisms (metabolism vs. cometabolism) and/or multiple TCE sources (see Appendix F for details). Knowledge of local hydrostratigraphy and groundwater flow directions (such as the orientation of less permeable soil layers and groundwater flow onto the site from the south) is used as a supporting line of evidence to aid in interpretation of any clustering patterns along the regression line.

As can be seen on Figures 6-14 and 6-15, many of the data line up in a linear fashion, exhibiting a lone kinetic isotope effect and uniform biodegradation occurring site-wide (see Section 6.5), but there are some observations that consistently are outside of the linear trend. For the most part, there is good correlation of the majority of the data points in the August  $\delta^{37}\text{Cl}$  plot, but poor correlation for the remaining plots (December  $\delta^{37}\text{Cl}$  and both rounds of  $\delta^{13}\text{C}$ ), suggesting more than one TCE fingerprint, thus more than one source of TCE in groundwater at OPHA. MCH-2LA had a large unexplained statistical variation for December  $\delta^{37}\text{Cl}$  and both rounds of  $\delta^{13}\text{C}$ , indicating that this point is probably a separate TCE source (see Appendix F for details). Two other wells, MCH-5UA and 87B1, consistently plot away from the general group of wells exhibiting the linear kinetic isotope effect configuration (see Figures 6-14 and 6-15), indicating another separate TCE source.

An additional evaluation of the data was performed to substantiate whether different TCE sources exist in groundwater underlying OPHA.  $\delta^{37}\text{Cl}$  and  $\delta^{13}\text{C}$  values were removed sequentially from the linear regression and re-evaluated to determine the relative impact of the isotopic data that plot outside of the general group of wells along the linear kinetic isotope effect trendline (see Appendix F for details). The results of this revised evaluation suggest that groundwater in the vicinity of the wells exhibiting the linear kinetic isotope trend has originated from the same TCE source.

As a result of the isotope analysis, three groups, which may represent different sources and different groundwater flow regimes, have been identified as follows.

- Group 1 - MCH-1UA, - 3UA, -4LA, -6LA, -7UA, -9UA, -10LA, 11UA (located along the southern OPHA boundary and throughout the southern two-thirds of OPHA)
- Group 2 - MCH-5UA and 87B1 (located 100 feet from the eastern OPHA boundary and 200 feet upgradient of the south eastern OPHA boundary, respectively)
- Group 3 - MCH-2LA (located 250 feet north of the south western OPHA boundary)

There was an initial uncertainty regarding the findings that MCH-2LA was an independent group - Group 3. Unlike the results for the groundwater monitoring wells in Groups 1 and 2, which were consistently observed as distinct isotopic signature groups on all four isotope plots, MCH-2LA plotted within Group 1 on the August  $\delta^{37}\text{Cl}$  data (see Figure 6-14). Isotope variability is not unexpected if the TCE observed in MCH-2LA is the fringe of a unique TCE plume originating off site and southwest of OPHA. Wells within the outer fringe of a plume typically are much more variable than wells situated deep within a plume due to being more sensitive to subtle changes in hydrologic conditions. Such variations in stable isotope values at plume fringes have been noted in the literature (Hunkeler et al., 2004).

Isotope analysis without original source material is an indirect interpretation. For it to be possible that there is only one upgradient source, given the isotopic ratio signatures seen in the data, variable biodegradation rates would have to be present within OPHA and evident in the data. However, there are no site-specific geochemical data that support such a theory. Additionally, there are no indications in the isotope data to suggest localized unique and/or multiple biodegradation rates since only one kinetic isotope effect was noted among all wells across the entire site. Therefore, the stable isotope data are interpreted to show three different TCE sources. This interpretation is combined with supporting site-specific geochemical and hydrogeologic data and is used to develop the CSM.

## **6.5 CONCEPTUAL SITE MODEL**

The CSM is described by defining 1) the movement of groundwater, 2) the distribution of contaminants, 3) potential sources of the contaminants, and 4) a set of circumstances that describes the fate and transport of the contamination.

### **6.5.1 Groundwater Movement**

The movement of groundwater and associated contamination is primarily influenced by the hydrostratigraphy of the site. The upper and lower portions of the A aquifer are distinguished hydrostratigraphically by the grain size of the soil. The upper and lower portions of the A aquifer are not two units separated by a layer of low permeability (aquitard). The upper A aquifer consists of interconnected coarser-grained sands and gravel with layers of finer-grained



silty sand and sandy silt, thus providing a preferential migration pathway from south to north across the site. The lower A aquifer generally consists of finer-grained silty sand and sandy silt that are not as laterally extensive or as interconnected as upper A aquifer coarse-grained soil layers. The lower A aquifer contains more extensive silt layers than the upper A aquifer.

Groundwater was encountered under semi-confined to confined conditions at most locations across OPHA. The semi-confined to confined conditions are consistent with groundwater encountered throughout Moffett. The flow directions within each portion of the A aquifer are influenced by the local hydrostratigraphy. Because of the interconnection of coarse-grained soil layers within the upper A aquifer, groundwater flow in the upper A aquifer is relatively consistent across OPHA from south-southeast to north-northwest with a potentiometric surface gradient of 0.007 ft/ft. Finer-grained soil in the lower A aquifer cause the general north-northwest groundwater flow direction to shift to the north-northeast in the west-central portion of the site (see Sections 5.4.2 and 5.5.2). Because of the finer-grained deposits within the lower A aquifer, the potentiometric surface gradient in the lower A aquifer varies from 0.0065 to 0.01 ft/ft.

The potentiometric surface gradients of the upper and lower portions of the A aquifer are generally similar. However, the lower A aquifer generally has finer-grained and less interconnected soil layers, suggesting that the groundwater flow rate should be slower in the lower portion of the A aquifer compared to the upper portion of the A aquifer. Based on the hydrostratigraphy, the potentiometric surface gradients, and the vertical hydraulic head potentials, the primary flow across OPHA is essentially horizontal with a downward component from the upper portion of the A aquifer to the lower portion of the A aquifer.

### **6.5.2 Distribution of Contamination**

Groundwater contamination at OPHA consists primarily of TCE and its breakdown product cis-1,2-DCE. Concentrations of TCE are generally higher in the lower portion of the A aquifer than in the upper portion of the A aquifer. TCE concentrations in the upper portion of the A aquifer are generally uniform from the south to the north across OPHA along the interconnected coarse-grained layers (see Figure 6-5). TCE concentrations in samples collected from the lower portion of the A aquifer generally increase from the southwest to the northeast across the central OPHA (see Figure 6-6).

TCE and cis-1,2-DCE distribution patterns in the upper A aquifer are similar (see Figures 6-5 and 6-7). Both TCE and cis-1,2-DCE in the upper A aquifer are migrating onto OPHA along the upgradient boundary, have relatively consistent concentrations from the southern to the northern OPHA boundary, and migrate onto NASA property. TCE and cis-1,2-DCE distribution patterns in the lower A aquifer are also similar (see Figures 6-6 and 6-8). Both TCE and cis-1,2-DCE are migrating onto OPHA along the upgradient boundary in both the upper and lower portions of the

A aquifer. Neither TCE nor cis-1,2-DCE migrate off OPHA onto NASA property in the lower portion of the A aquifer.

### 6.5.3 Potential Sources of Contamination

The stable isotope data are interpreted to show three different sources of TCE impacting the groundwater beneath OPHA (see Section 6.4).

**Source 1** – is identified by the  $\delta^{37}\text{Cl}$  and  $\delta^{13}\text{C}$  values observed in eight out of 11 wells across the site (Group 1, Section 6.4). Since the  $\delta$  values for Source 1 are found in the upgradient OPHA groundwater monitoring wells MCH-1UA, MCH-3-UA, and MCH-4LA, this TCE source originated off-site to the south of OPHA and is migrating onto OPHA.

An upgradient source south of OPHA is reasonable for Group 1 monitoring wells MCH-7UA and MCH-11UA, located in the center of OPHA, based on the interconnected coarse-grained layers in the upper A aquifer, groundwater flow direction, and the detected TCE concentrations. The remaining three Group 1 monitoring wells, MCH-6LA, MCH-9UA, and MCH-10LA, have higher TCE concentrations than upgradient monitoring wells, which does not appear to be consistent with an upgradient source. However, there are several supporting lines of evidence that explain the higher TCE concentrations at these locations relative to the upgradient wells, particularly if slug type flow is assumed (see Section 6.5.4): 1) the northeastern groundwater flow direction in the lower portion of the A aquifer in the central part of OPHA; 2) fine-grained soils at or near these well locations that probably adsorbed higher concentration of TCE when a slug first passed through the area and are now releasing these adsorbed chlorinated compounds in response to equilibrium conditions; and 3) the apparent TCE releases south of OPHA (based on Army and EPA data). An on-site source is not reasonable at any of these locations, including the slightly higher TCE concentrations in samples collected from monitoring wells MCH-6LA, MCH-9UA, and MCH-10LA.

Based on the geographic location of the eight Group 1 wells (along the upgradient OPHA boundary and throughout the southern two thirds of OPHA), the upper and lower A aquifer TCE and cis-1,2-DCE distribution patterns, the upper and lower A aquifer hydrogeology, and upper and lower A aquifer groundwater flow direction, Source 1 originates off-site and south of OPHA. Possible sources include activities within the Highway 101/Moffett Boulevard interchange, the Santa Clara County vector control yard, the historic/current dry cleaners located on Fairchild Drive near Evandale Avenue, or from an unknown upgradient source. Since PCE is only detected in samples collected from well MCH-3UA and Army samples SIG10, SIG13, and SIG14, it is likely that the historic/current dry cleaners contribute as a part of Source 1.

**Source 2** – is identified by the  $\delta^{37}\text{Cl}$  and  $\delta^{13}\text{C}$  values observed in two of the 11 wells on the eastern side of OPHA and southeast of OPHA (Group 2, Section 6.4). Well MCH-5UA is upgradient wells to OPHA (due to the local north-northwestern groundwater flow direction).

Well 87B1 is cross-gradient to OPHA. Since the  $\delta$  values for Source 2 are found in cross-gradient or upgradient groundwater monitoring wells, and only in the two wells near the eastern OPHA boundary, an on-site source is not reasonable for Source 2. This TCE source originated off-site to the south-southeast of OPHA. Based on the location of the two Group 2 wells, the upper and lower A aquifer TCE distribution patterns, the upper and lower A aquifer hydrogeology, and upper and lower A aquifer groundwater flow direction, Source 2 originates off-site and southeast of OPHA. Possible sources include the commingling of Source 1 with the western edge of the regional VOC plume (in the lower portion of the A aquifer), the western edge of the regional VOC plume (in the lower portion of the A aquifer), the Highway 101/Moffett Boulevard interchange, the historic/current dry cleaners located on Fairchild Drive near Evandale Avenue, or from an unknown upgradient source.

**Source 3** – is identified by the  $\delta^{37}\text{Cl}$  and  $\delta^{13}\text{C}$  values observed only in well MCH-2LA located in the southwestern portion of OPHA (Group 3, Section 6.4). There are some uncertainties regarding the findings for MCH-2LA. Unlike the other 10 OPHA wells that were consistently observed as Group 1 or 2 on all four isotope plots, MCH-2LA plotted within Group 1 on the August  $\delta^{37}\text{Cl}$  data plot (see Figure 6-14). However, isotope variability is not unexpected if the TCE observed in MCH-2LA is the fringe of a unique TCE plume. Based on isotope data on three of the four plots, Group 3 could be caused by a different source originating off site to the southwest of OPHA and/or localized enhanced reductive dechlorination (see Section 6.1.2). Hydrogeologic and geochemical data collected during this investigation supports an off-site upgradient location for Source 3. An on-site source would have to migrate through the upper A aquifer before impacting the lower A aquifer. If an on-site TCE source existed in the area of MCH-1UA/2LA, it is reasonable to assume that upper A aquifer well MCH-1UA, located 5 feet east from lower A aquifer well MCH-2LA, would have a similar isotopic fingerprint. However, upper A aquifer well MCH-1UA consistently plotted within Group 1. This would suggest that Source 3 is from an off-site upgradient source, southwest of OPHA. There are no data to suggest localized enhanced reductive dechlorination in the area of well MCH-2LA.

Some information from previous investigations could be interpreted as evidence of an on-site source. However, when combined with current site information, the presence of an on-site source is not supported. The previous data are as follows:

- An aerial photograph from 1956 shows a road leading to a surface disturbance and possible structures to the north of the present day MCH-1UA/2LA area (FWENC, 2002b). Although the surface disturbance was still visible in a 1958 aerial photograph, the road was not. Subsequent photographs through 1982 (when housing development in this area commenced) show a variation in surface color in the area of the 1956-1958 surface disturbance. The nature of the surface disturbance and variation in color is unknown. Assuming a TCE release occurred in 1956-1958 or if the discoloration visible in the subsequent photographs was caused by repeated TCE releases, the upper and lower portions of the A aquifer would be impacted. TCE would have migrated downgradient during the 50 years since the release and

additional distinct  $\delta^{37}\text{Cl}$  and  $\delta^{13}\text{C}$  values would be expected in upper and lower A aquifer wells downgradient of the disturbed area. However, TCE from groundwater samples in all upper and lower A aquifer wells, downgradient of the surface disturbance area, consistently plot within Group 1 wells, which are impacted by an off-site upgradient source (Source 1). Therefore, the historical aerial photograph information combined with all other site data does not support the existence of an on-site source.

- Soil core field screening using a PID detected organic vapors between 9.2 and 3,500 parts per million from 5 to 13 feet bgs at FW41A (see Section 1.2.1.1). FW41A is located approximately 75 feet southeast of MCH-1UA/2LA, near the southern extent of the historical surface disturbance observed in the 1956 and 1958 aerial photographs. A PID is a field screening tool and is not chemical-specific. The nature of the organic vapor detected at FW41A is not known. FW41A is located in the street, approximately 5 feet from the curb, in OPHA. The high PID readings could have been the result of a localized motor vehicle fuel spill and not necessarily evidence of a TCE release (however, fuel components [benzene, toluene, ethylbenzene, or xylene] were not detected in any OPHA groundwater samples – suggesting that there has not been a motor vehicle fuel spill). Assuming the elevated PID readings were evidence of an on-site TCE release, the upper A aquifer groundwater would be impacted first as the release migrated through the soil column. If the release volume was sufficient to migrate through the upper A aquifer, the lower portion of the A aquifer would also be impacted. In either case, additional distinct  $\delta^{37}\text{Cl}$  or  $\delta^{13}\text{C}$  values would be expected in the upper A aquifer near, and downgradient of, FW41A. However, TCE from groundwater samples in all upper and lower A aquifer wells, downgradient of FW41A plot within Group 1 wells, which are impacted by an off-site upgradient source (Source 1). Therefore, elevated FW41A PID reading combined with all other site data does not support the existence of an on-site source.

It could be argued that the CSM (see Section 6.5.4) supports the possibility of an on-site release being detected in the lower portion of the A aquifer (MCH-2LA) but not the upper portion of the A aquifer (MCH-1UA). As described in the CSM, groundwater flows faster in the upper portion of the A aquifer than in the lower portion of the A aquifer due to a wider distribution of interconnected coarse-grained soil layers in the upper A aquifer. Therefore, a TCE release in the upper A aquifer would move quickly downgradient, while lower A aquifer TCE migration would be slower. TCE may not be detected in the upper A aquifer in a well pair located near an on-site source area because the TCE would have migrated downgradient. The TCE would be detected in the lower A aquifer due to the slower migrations rate. However the upper A aquifer TCE plume would show up as additional distinct  $\delta^{37}\text{Cl}$  and  $\delta^{13}\text{C}$  values in downgradient wells. TCE from groundwater samples in all upper and lower A aquifer wells downgradient of MCH-1UA/2LA plot within Group 1 wells, which are impacted by an off-site upgradient source (Source 1). Therefore, the CSM does not support the existence of an on-site source at this location.

#### 6.5.4 Contaminant Fate and Transport

A CSM has been developed to illustrate the release, migration, and the eventual fate of groundwater contamination (Figure 6-16). The CSM takes into account the upper and lower A aquifer VOC distribution patterns, hydrostratigraphy, the likely hydraulic parameters within each aquifer layer, groundwater flow directions, and the results of the stable isotope study. Important elements of this model include the following:

- The primary source of TCE detected throughout OPHA (Source 1) is located south of the site.
- The A aquifer consists of two portions that are hydraulically connected, yet hydrostratigraphically different, primarily by grain size and continuity: the upper A aquifer consists of interconnected coarser-grained sands and gravel; the lower A aquifer generally consists of finer-grained silty sand and sandy silt that are not as laterally extensive or as interconnected.
- The groundwater flow rate is faster in the upper portion of the A aquifer than in the lower portion of the A aquifer.
- TCE and cis-1,2-DCE concentrations are well-distributed in the upper A aquifer from the north to the south across OPHA. TCE concentrations increase from the south to the central portion of OPHA in the lower A aquifer.
- Elevated TCE concentrations appear as slightly elevated concentrations within OPHA, which is related to fine-grain soils near elevated concentration sampling locations and sorption/desorption of contaminants.

These elements, when combined, support the interpretation of one or more “instantaneous” off-site release(s) of TCE south of OPHA. The instantaneous release(s) occurred for a short period of time and is responsible for the majority of the detected OPHA TCE (Source 1, Section 6.5.3). The TCE migrated downward to the water table and was distributed vertically throughout the coarser-grained soil of the upper A aquifer and the finer-grained soil of the lower A aquifer. Residual soil contamination contributed to groundwater contamination until no further leaching of TCE from soil to groundwater occurred. Instantaneous point source release(s) with resulting slug flow is well documented in the literature (Freeze and Cherry, 1979).

The resulting groundwater TCE “slug” migrated downgradient within the upper and lower A aquifer with residual contamination from the source and the tail of each slug stretching back to the source area. The resulting slug(s) moves at different rates: faster in the upper portion of the A aquifer compared to the lower portion. Eventually, over time and distance, the contaminant slug segments lose mass as they are subjected to the chemical and physical processes of degradation, dilution, dispersion, and sorption within the aquifer. In the upper A aquifer (as shown in Figure 6-16), because of the higher transport rate and lower retardation, the slug(s) have migrated through and past OPHA, leaving only the residual “tail of the TCE plume. An exception to the slug migrating past OPHA in the upper A aquifer is the slug remnant appearing

as an elevated concentration at MCH-9UA. In the lower A aquifer (as shown in Figure 6-16), because of the slower transport rate and higher retardation, the slug(s) have migrated onto OPHA, and portions are still present as elevated concentrations. Such a condition would explain the increase in TCE concentration in the lower A aquifer downgradient wells MCH-10LA and MCH-6LA.

The CSM is supported by multiple lines of evidence that include: 1) local hydrostratigraphy (developed with multiple CPT and continuous core geologic logs); 2) upper and lower A aquifer VOC concentration trends and distribution patterns (supported by multiple on- and off-site groundwater sampling events); 3) local groundwater flow direction (calculated using data from 11 monitoring wells and knowledge of local hydrostratigraphy); 4) regional groundwater flow direction (based on Black Thursday measurements); 5) stable isotope study results; and 6) historical and current land use.

## 7.0 CONCLUSIONS

Eleven monitoring wells were installed at OPHA between July 11 and July 21, 2005. Six wells were screened in the upper portion of the A aquifer. Five wells were screened in the lower portion of the A aquifer. Four rounds of groundwater monitoring well gauging and sampling were completed (August and December 2005, and March and June 2006). Based on the results of previous on- and off-site investigations and the implementation of the *Final Groundwater Monitoring Well Installation and Sampling Work Plan for Orion Park Housing Area* (TtFW, 2005), TCE and cis-1,2-DCE detected at OPHA originates off site and upgradient. No on-site TCE sources have been identified. The following additional conclusions are presented:

### 7.1 HYDROSTRATIGRAPHY

Three primary conclusions are drawn from the evaluation of subsurface data:

- The A aquifer consists of two portions that are hydraulically connected, yet hydrostratigraphically different, primarily by grain size and continuity.
- Groundwater flow in the upper A aquifer is relatively uniform across OPHA from south-southeast to north-northwest.
- Groundwater flow in the lower A aquifer changes from the north-northwest in the southern portion of OPHA to the north-northeast in the west-central portion of OPHA.

### 7.2 TCE AND CIS-1,2-DCE DISTRIBUTION

Two primary conclusions are drawn from the groundwater data collected in and around OPHA:

- TCE and cis-1,2-DCE are migrating onto OPHA in the upper and lower portions of the A aquifer, across the southern border.
- The TCE and cis-1,2-DCE migration pathway follows the coarse-grained soil layers and the groundwater flow direction.

### 7.3 TCE SOURCE IDENTIFICATION

Two primary conclusions are drawn from the stable isotope study:

- Stable isotope data are interpreted as showing three distinct TCE sources.
- The three sources (Source 1, 2 and 3), originate off site and upgradient to the south, southeast, and southwest of the site, respectively.

No on-site TCE sources have been identified, and there is no evidence to suggest an on-site source.

## 7.4 CONCEPTUAL SITE MODEL

Four primary conceptual site model conclusions are drawn from combining all lines of investigative evidence:

- Instantaneous or short-time off-site release(s) (“slug release[s]”) of TCE occurred south of OPHA.
- Contamination migrated downgradient at different rates: faster in the upper portion of the A aquifer; slower in the lower portion of the A aquifer.
- Contaminant slug(s) have migrated through OPHA in the upper A aquifer leaving a residual “tail” and slug remnant(s) observed as slightly elevated concentrations.”
- Contaminant slug(s) have migrated onto OPHA in the lower A aquifer, and portions are still present as slightly elevated concentrations.



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